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WILDFLOWERS FOR INDIANA HIGHWAYS

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PURDUE UNIVERSITY

FINAL REPORT

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FOR INDIANA HIGHWAYS

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16. Abstract <p>Questions concerning wildflower usage on Indiana highway rights-of-way were investigated. Native prairie wildflower seed quality was found to be highly variable among supply companies, species, and years. Less variability was found among "garden" wildflower species and suppliers.</p> <p>Direct seeding was found to be successful with six species of native prairie forbs: Butterfly Milkweed <i>Asclepias tuberosa</i>, Wild Bergamot <i>Manarda fistulosa</i>, New England Aster <i>Aster novae-angliae</i>, Pale-purple Coneflower <i>Echinacea pallida</i>, Gray-headed Coneflower <i>Ratibida pinnata</i>, Ironweed <i>Vernonia fasciculata</i>.</p> <p>Five species of "garden" wildflowers performed well: Common Cosmos <i>Cosmos bipinnatus</i>, Yellow Cosmos <i>Cosmos sulphureus</i>, Cornflower <i>Centaurea cyanus</i>, Goldenwave <i>Coreopsis tinctoria</i>, Black-eyed Susan <i>Rudbeckia hirta</i>. Significant variation was found for species establishment success with respect to soil type.</p> <p>Seedling transplanting was found to be a successful method for establishment of forb species, especially those that are difficult to establish by direct seeding. Eight-inch deep seedling tubes increased plant survival compared to plants produced in five inch deep tubes. Use of water-holding polymers in the growing medium, or inoculation with vesicular-arbuscular mycorrhizal fungi did not improve forb transplant survival. VAM inoculation did result in larger plants after the first growing season.</p> <p>The costs of establishment and management of wildflowers varied with the type and management strategy. Wildflowers were found to be cost-effective when compared to the current grass monoculture vegetation strategy used by INDOT. "Garden" wildflowers were less costly to establish, but were more costly on an annual basis. Prairie plant community wildflowers were more costly initially, but became cost effective when low, long-term management costs were factored into the analysis.</p>					
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IMPLEMENTATION

These study results form a solid basis upon which INDOT can initiate a limited highway right-of-way wildflower program. However, although this study has answered some basic questions, it leaves many more questions unanswered concerning many specific planting and management alternatives. It has also been limited geographically, so there is room for some concern over the applicability of all the study's findings system-wide. However, putting these concerns aside, a limited program of wildflower implementation is very feasible at this time.

Indiana's highway wildflower program should be focused primarily on native, perennial, prairie forb and grass species. Seed is readily available, although the cost is substantial, especially in view of the variability in quality. For the present, INDOT should continue to work with several seed suppliers. INDOT should push to implement the seed quality recommendations found in this report. However, some of them will require time to be put in place. District Landscape Supervisors and planting contractors should be encouraged to make careful records of their seed sources in relation to planting successes or failures. This will help guide future purchases.

Several alternatives for seed acquisition exist. INDOT should consider undertaking its own seed production, or actively coordinating with other interested agencies, to develop its own internal seed stocks for highway planting. Once substantial areas of native species are established, they provide a seed source which can be harvested and used to expand plantings.

INDOT already has the basic tools, in the form of Truax seed drills, available to undertake a direct seeding wildflower program. Direct seeding into clear, untilled soil, during the late fall or early winter, is a good way to proceed. If a selected planting site's soil is extremely compacted it would be wise to choose an alternative location.

The issue of exactly what to plant and in what relative proportions is a sticky one. The species to start with are those listed in the recommendations section of this report. Until more research is conducted on mixes, etc. a reasonable approach would be to use the mix described in the cost estimation section of this report. It is based on the authors' judgement, not experimentation. Like other aspects of the Indiana wildflower program at present, it should be implemented only on a limited basis.

INDOT can achieve significant impact in limited areas quite rapidly by implementing a wildflower transplant program for rest parks, high visibility intersections, etc. Transplants should also be planned as a means to enrich species diversity in plantings that are done by direct seeding. A growing number of producers are offering native seedlings in containers such as the Stewe tube type used in this work, that have proven to be a successful means to plant establishment. A transplant program should be conducted at the District level, with long lead

time to allow plant production specifically for a given project and to allow for installation at the proper time of the season to maximize success.

Transplants need not be produced in greenhouses. Native wildflower seed germinates readily after being subjected to natural winter conditions for stratification. Seedlings can be grown on for several months and installed the same growing season. INDOT should consider undertaking a limited plant production program under the direction of the District Landscape Supervisors at the District garages. All that is required besides growing tubes, media and seed (all of which is readily available on the market) is a paved surface, a tarp for winter covering, and a source of water for irrigation once plant growth begins in the spring. Seedling produced in this manner are very flexible and can be held in the containers for many months without loss of viability. Having a ready supply of plants in-house, INDOT would be in a position to take advantage of available labor such as volunteers or slow time in the regular activities of full-time employees for plant installation.

Garden wildflowers should continue to be a part of the INDOT planting program. Seed quality for these species is relatively reliable and consistent. Specific areas should be designated as wildflower plantings for the long-term future. Excellent site preparation, in terms of complete weed removal should be accomplished before any seeding. Areas should be established with the intent that they will be replanted regularly (every 1 - 3 years) and regularly managed to avoid weediness. Herbicide usage should be considered as our knowledge increases concerning usable materials. Plantings should be very limited in species diversity and carefully planned to take greatest advantage of sight lines for the maximum impact on motorists. The species recommended in this report are the ones on which to concentrate, but other species may provide excellent results, so experimentation by Landscape Supervisors should continue. Planting can be done with the same equipment already mentioned above, and late-spring planting (May) for the warm season species has been shown to be satisfactory.

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CHAPTER 1

INTRODUCTION

1.1. General

A superior public highway system requires a roadside vegetation management program which results in stable grades on all soil surfaces and clear zones adjacent to the roadway, with attractive and diverse views for the motorist. The program should accomplish these results at the lowest cost to the taxpayer.

The current roadside vegetation management program for Indiana highways emphasizes mowed turfgrass. This approach provides excellent clear zones adjacent to roadways. However, the turfgrass presents a uniform mowed appearance that results in visual monotony for the motorist. Also, frequent mowing is relatively expensive in terms of labor and equipment costs. In addition, regular use of pesticides for broadleaf weed control in the turfgrass is costly and is potentially an environmental hazard.

An alternative, or supplement, to the mowed turfgrass program on Indiana highways is the use of herbaceous plantings composed of ornamental, visually attractive wildflowers. Herbaceous plants form no woody stems and die to the ground each year, so clear zones adjacent to the roadways are easily maintained. Certain species of wildflowers, especially those native to central North America, often survive and flourish with very little annual maintenance. Many wildflowers produce colorful flowers which relieve visual monotony and enhance the motoring experience. This is especially true when wildflower are established as communities of species. The species diversity provides changing color and visual patterns throughout the growing season, making the experience for the repeat motorist (commuters, etc.) more enjoyable. Conversion to wildflowers of some roadsides is a means for Indiana to reduce roadside maintenance costs, enhance the state's image for visitors and residents, and promote environmental quality through decreased fossil fuel and pesticide usage.

1.2. Problem Statement

Public demand for efficient use of tax dollars, increasing public and governmental insistence on environmental protection and biodiversity, federally mandated highway roadside wildflower usage, and successful changes in the roadside vegetation management strategies of numerous other states, both neighboring Indiana and nationwide, are all reasons why it is desirable for the Indiana Department of Transportation to study the use of herbaceous plants and plant communities as an alternative, or supplement, to the current highway roadside vegetation management program.

The specific problem which this study has addressed is:

What are appropriate wildflower species for use on Indiana roadsides, and how can they be economically and efficiently established on Indiana highway rights-of-way?

Two classes of wildflower vegetation are defined for purposes of this research. Both consist only of herbaceous plants, that is plants which die to the ground at the end of each growing season and have no persistent, above-ground, woody plant parts.

"Garden" wildflowers are dicotyledons (broadleaves), which may be native to Indiana, or of non-native origin. They are generally horticulturally developed species that are quite ornamental. However, they often have a one or few year useful life expectancy due to their inherent life cycles or their relative non-competitiveness with weedy species. Over the long term, they can be demanding of relatively costly inputs for management and repeated establishment. Such higher costs may be justified in limited areas because of their greater visual impact.

"Native" wildflowers are defined as those species which are thought to have occurred in Indiana or the bio-region of the tall grass prairie c.1800. They are visually attractive, but often in a more subtle manner than "garden" species. Both mono- and dicotyledons (grasses and forbs) are included in this class of wildflowers. However, in this study, experimentation was focused heavily on forbs. They generally exhibit a perennial plant habit, that is, one in which the life-span exceeds two years. Once established, it is a reasonable expectation that these species can persist indefinitely as plant communities with only minimal management inputs.

1.3. Objectives and Scope

The specific objectives of this research were as follows:

1. Evaluate the quality of wildflower seed produced by a sampling of existing and potential commercial suppliers to INDOT projects.
2. Determine the suitability for: a) establishment by seeding, and b) performance of 10-20 species of "garden" wildflowers.
3. Determine the suitability for: a) establishment by seeding, and b) performance of 10-20 species of "native" wildflowers.
4. Investigate non-traditional planting methods for their usefulness in establishment of "native" wildflower species.
5. Predict the costs of implementation for several establishment strategies for both "garden" and "native" wildflowers.

A review of the previous experimental research in highway and restoration wildflower work is presented in Chapter 2. Chapter 3 describes the experimentation that was conducted to determine the level of seed quality being provided by commercial wildflower seed producers. Two year's results from direct seeding experiments in both "garden" and "native" wildflowers on Indiana highway rights-of-way are presented in Chapter 4. Several aspects of wildflower establishment by transplants were investigated and are discussed in Chapter 5. Although no conclusive scenarios for statewide wildflower usage are possible at present, a potential scheme is investigated relative to estimated costs of implementation and long-term management in Chapter 6. Chapter 7 presents conclusions, implementation suggestions and a look at additional research needed to move INDOT into a position to confidently adopt wildflower usage throughout Indiana's highway system.

CHAPTER 2

LITERATURE REVIEW

2.1. General

A wildflower is "in the eye of the beholder." The term is non-specific, except to imply a plant that grows without human assistance. Even that definition is inaccurate in the context of the landscape planting of "wildflowers." Herein, a wildflower is a native Indiana prairie plant. However, it is also any flower that is called a wildflower, intended to be grown in a "wild" manner, and which might be considered for growing on a highway right-of-way.

2.1.1. Origins of the Prairie

The term prairie is applied to what was a vast community of grass, flower, and animal associations uniquely adapted to the environment of the Great Plains region of the United States. Little remains today. The renowned prairie researcher, J.R. Weaver wrote the prairie "was born out of ecological adaptation, and destroyed by economic reality".

The North American Prairie originated during the Tertiary Period of geologic history 25 million years ago (Weaver, 1954). During this period, the uplifting Rocky Mountains reduced precipitation to land areas east of the mountains. Forests occupying these areas gradually disappeared. An extensive grassland better adapted than forests to reduced precipitation conditions subsequently developed from the Rocky Mountains east to present-day Ohio, north into Canada, extending south to Texas (Costello, 1975).

The prairie was a vast community of herbaceous perennial plants (Weaver, 1954). Deep-rooted grasses and flowering herbaceous broadleaf plants (called "forbs") formed a thick mat of sod which conserved water and enriched the soil. The "prairie" consisted of approximately 250 species of grasses and forbs occupying over a billion acres (Steiger, 1930; Weaver and Fitzpatrick, 1934).

2.1.2. Destruction of the Prairies

Overgrazing, agronomic and urban development, and drought have virtually eliminated prairie as a vegetational type in the United States (Costello, 1975). The Homestead Act of 1862 opened prairie land for settlement by eastern U.S. and European immigrants. Introduced cattle and sheep grazed heavily on the prairie grasses. Millions of acres of prairie were plowed to grow food for an expanding population. Prolonged droughts resulted in the "Dust Bowls" of the 1930's and were a final death blow to many large areas of prairie remaining in the United States (Weaver, 1954).

Small prairie "remnants" survived along undisturbed railroad rights-of-way, abandoned and unmowed cemeteries, early roads, and undisturbed fields. However, since the 1930's, roadside vegetation managers have used herbicides and mowing to eliminate prairie remnant areas located near previously undisturbed areas (Costello, 1975). Today, less than one-tenth of one percent of the original prairie remains (Drobney, 1994).

2.1.3. Restoration of Prairie Ecosystems

Restorationists' efforts to rebuild prairie ecosystems began in 1930 when John Curtis established what came to be called the Curtis Prairie at the University of Wisconsin Arboretum. Ironically, Curtis began his establishment of the prairie at the same time prairie remnant areas located near highway rights-of-way were rapidly disappearing. Henry Greene established another 20 ha prairie (also at the University of Wisconsin) using procedures established by Curtis (Kline, 1992). Katherine Ordway supported nature conservancy efforts to save prairie remnant sites in the Midwest (Madson, 1994).

Floyd Swink and Ray Schulenberg led early efforts to restore prairies in the Chicago area. Both Swink and Schulenberg documented prairie restoration and propagation techniques for particular prairie species while restoring a prairie at the Morton Arboretum (Bonta, 1991). Carl Betz of Northeastern Illinois University obtained permission to establish a prairie at the 2475 ha Fermilab National Accelerator Ring near Chicago in 1975. Betz has popularized the prairie and is a leading authority on prairie establishment methods (Betz, 1986).

2.1.4. Classic Research on Prairie Ecosystems

Quantitative research on prairie ecosystems began in the early 1900's. Early researchers concentrated their efforts on the classification of species within the prairie and prairie ecology. Shimek (1911) classified at least 265 unique species of prairie plants while visiting at least 60 prairie sites in Iowa. In Minnesota, Moyer (1910) characterized different types of prairie (high rolling prairie, valley and prairie meadow, prairie sloughs).

Researchers at the University of Nebraska studied prairie ecology, identification of prairie plants, and competition between prairie, woodland, and weedy species (Clements, 1920; Weaver and Fitzpatrick, 1934; Hanson, 1938). J.E. Weaver was the first to produce a comprehensive study of prairie plant species, including the growth response of prairie species to the "Dust Bowl" drought during the Great Depression. Weaver investigated root morphology and forage capabilities of prairie grasses. He discovered that the roots of prairie species such as *Panicum virginicum* L. can extend down at least 3 m in the soil (Weaver, 1954; Weaver and Darland, 1949). Blake (1935) produced a classic monograph on seed germination of prairie species. Blake was the first to report that seeds of many prairie species required moist stratification to

enhance germination. She also studied the transplant survival of prairie species. Transeau (1935) presented a thorough study of the extension of the "prairie peninsula" into eastern deciduous regions during glaciation.

The establishment of the University of Wisconsin's Curtis Prairie began in 1930. Curtis created the first "artificial" prairie and documented the effects of particular prairie restoration techniques such as: weed control methods, the use of burning to eliminate woody plant invaders and herbaceous weeds, and seed and seedling establishment techniques (Sperry, 1982). Researchers at Wisconsin studied the long term effects of the distribution of prairie species, and reported that certain prairie species established stable populations, while other species tended to spread or decline (Kline, 1992).

The effects of fire on the prairie ecosystem has been investigated since 1930. Prairie fires occurred naturally with summer storms or were set deliberately by Native Americans in an attempt to rejuvenate the prairie while controlling weed invasion (Risser, 1981).

Anderson, *et al.* (1965) investigated the effects of fire on prairies located in the Flint Hills of Kansas. They discovered that spring burning of the prairie increased the biomass of warm-season perennial prairie grasses and resulted in reduced biomass of cool-season grasses such as *Poa pratensis* L. Anderson built upon the early work of Curtis because he demonstrated that burning promoted flowering of prairie species. The effects of fire have constituted a large portion of prairie research from 1970 to the present, with a concentration on the seasonal effects of burning and grazing on forage potentials of prairie grasses (Owensby and Smith, 1979).

2.1.5. Prairie Restoration Along Highways

Extensive "natural" areas of native vegetation existed on highway rights-of-way before 1920. Such areas remained "natural" because of limited resources and technology (Harrington, 1994). However, beginning in 1930, state and federal policies regarding roadside vegetation management changed. Federal and state highway officials believed that turf areas should be established near highways. They viewed turf areas as neater in appearance than native vegetation, allowing for greater visibility of the surrounding country-side (Harrington, 1994).

As early as 1940, objections were raised to turf establishment and removal of natural areas near highways. Prominent landscape architects O.C. Simonds, Jens Jensen, and Illinois extension educator Wilhelm Miller strongly objected to the aesthetics of mown turf near highways (Harrington, 1994). Ignoring restorationists' objections, federal highway officials continued to promote a policy of turf establishment and management along highway rights of way until 1960.

Federal roadside managers changed their roadside vegetation practices in the early 1960's for three reasons: growing public concerns regarding the environment, a change in political

attitude and policy, and a realization that energy costs made alternatives to turf establishment and maintenance more cost-effective (Harrington, 1994). President Lyndon Johnson issued the *Beauty for America* report in 1965. Johnson promoted the use of native vegetation along highways in response to changing American attitudes towards environmentalism (Johnson, 1965). The report marked the beginning of a renewed public interest in "wildflowers." State and federal officials began to re-assess the exclusive use of herbicides and mowing on highway rights-of-way.

Texas, in the 1930's, was the first state to begin preserving and restoring wildflower and prairie areas on highway rights-of-way. However, other states did not begin to change their roadside vegetation practices until the passage of legislation by the federal government. The Federal Highway Administration's promotion of "Operation Wildflower" suggested the use of native vegetation along highways. The passage of the Surface Transportation and Uniform Relocation Assistance Act of 1987 mandated a minimum amount of "wildflower" planting along highways (Harrington, 1994).

The Illinois Department of Transportation instituted a reduced mowing policy in 1975 and began efforts to restore prairie areas (Chaves, 1988). Dane County, Wisconsin citizens successfully lobbied for use of prairie wildflowers and limited mowing along highway right-of-ways in 1975 (Nuzzo, 1978). The state of Ohio instituted a state nursery to propagate wildflowers and provide seed to Ohio Department of Transportation (Clunk, 1994 personal comm.). The State of Indiana Department of Transportation, through informal cooperation with The Nature Conservancy, The Garden Clubs of Indiana, Inc., and The Indiana Department of Natural Resources, has also instituted a program of limited wildflower establishment along Indiana highways.

2.1.6. Wildflower Research Along Highways

Many states have instituted prairie restoration programs along highways, but little quantitative research has been published on this topic. Researchers have reported that mowing requirements for established prairie plantings along highways were less than conventional grass areas (Dolling and Landers, 1965). Prairie plantings installed on slopes controlled erosion (Sperry, 1935), and also were considered to be aesthetically pleasing alternatives to conventional grass plantings (Ode, 1972; Morrison, 1975). Established prairie areas resist the invasion of weeds compared with turf areas (Weaver and Flory, 1934), suggesting less need for herbicides to control weeds. Prairie grasses and forbs have been found to provide better food sources for wildlife compared to mown turf (Nichols and Entine, 1976).

State transportation officials have often used trial and error research methods to learn about wildflower establishment or have depended on commercial sources to help formulate

restoration programs. Such approaches can be expensive, time consuming, and wasteful, especially considering that highway rights-of-way usually offer difficult conditions for any plant establishment (Harrington, 1994).

The Indiana Department of Transportation has experimented with some aspects of a wildflower establishment program (Bickel, INDOT, pers. comm.), and some preliminary studies funded through the Joint Highway Research Project have begun to answer some of the many necessary questions (Curry, 1980). The specific areas of research described in this report involve a determination of the quality of commercially available wildflower seed, species adaptability to direct seed establishment, direct seed establishment method, transplant establishment alternatives to direct seeding, and projected implementation costs of a comprehensive highway wildflower program for Indiana.

2.2. Seed Quality Testing

Direct seeding techniques can be used to establish prairie and garden wildflowers along highway rights-of-way (Schram, 1978). Many factors are involved with direct seeding establishment success of wildflowers, but one factor which is often blamed for poor results is poor seed germination resulting from poor seed quality (Don Bickle, INDOT District supervisor, personal comm.). Companies that market wildflowers seed often provide little or no information about expected seed germination percentages to their customers.

Christiansen and Landers (1966) and Blake (1935) reported germination percentages of several prairie wildflowers. However, both studies reported germination percentages of seed collected from specific wild locations, used a variety of methods, and did not report germination percentages of seed obtained from commercial sources.

Well established procedures exist for the *in vitro* testing of agronomic and horticultural seed quality (USDA, 1993). Adaptation of those methods to wildflowers provides an avenue to begin to answer the following questions: Does seed quality vary between garden and prairie wildflowers? Does seed quality of a particular wildflower species vary among seed companies? Finally, does seed quality of the same wildflower species from a company vary from year to year?

2.3. Direct Seeding Establishment of Garden and Prairie Wildflowers

As previously noted, direct seeding techniques are often used to establish garden and prairie wildflowers along highway rights-of-way (Schram, 1978). Wildflowers can be seeded as flowers only, or in mixes with native grasses (Salac *et al.*, 1982). Many different wildflower seeding techniques exist and several have been evaluated. These techniques include:

hydroseeding (Betz, 1986), seed drilling (Schramm, 1970; 1978; Betz, 1986), hand broadcasting (Schramm, 1970; 1978), and mechanical broadcasting (Betz, 1986). Some evaluation has also been done for machinery commonly used to seed wildflowers (Schramm, 1972; Vassar, *et al.*, 1981; Betz, 1986; Thomas, 1988; Wiedemann, 1988).

Many site preparation techniques exist for the establishment of wildflowers. Proper site preparation can lead to reduced weed competition and increased stand establishment of wildflower species (Schramm, 1970; 1978). Techniques investigated to date include: herbicide use prior to planting (Woehler and Martin, 1978; Evans, 1981; Bragg and Sutherland, 1989), various combinations of plowing, discing, harrowing, and firming (Schramm, 1970; 1978; Woehler and Martin, 1978; Vassar, *et al.*, 1981), use of cover crops (Schwarzmeier, 1972; Vassar, *et al.*, 1981), and bulldozer use for problematic stands of invasive woody plants (Widstrand, 1982).

As previously mentioned, seed conditioning, viability, and germination are a few of the most important factors in direct seeding establishment of wildflowers (Blake, 1935; Christiansen, 1967; Salac and Hesse, 1975; Schramm, 1978; Salac *et al.*, 1982). Poor establishment of many wildflower species is related to issues such as weed competition (Schwarzmeier, 1972; Schramm, 1978), timing of seeding (Salac *et al.*, 1982; Whitney, 1983; Zajicek, *et al.*, 1986), and seed quality (Salac and Hesse, 1975; Schramm, 1978; Heston, *et al.*, 1983).

The effects of mulching with straw, marsh hay, prairie hay, and woodbark on direct seeding establishment of selected wildflowers and grasses has been investigated (Ode, 1970; Kuenstler *et al.*, 1981). In some cases mulches have proven beneficial in the establishment of various wildflowers. The effects of mulch in the form of dead, untilled vegetative remains resulting from herbicide pre-treatment and no follow-up tillage have not been investigated. Further areas requiring investigation include the effects of seeding depth on stand establishment of various wildflower species.

Timing of seeding for selected wildflower species has been investigated (Salac *et al.*, 1982; Whitney, 1983; Zajicek *et al.*, 1986). Some species, such as *Asclepias tuberosa* and *Echinacea angustifolia*, germinated at higher rates when planted in the fall (October-November). Other species, such as *Petalostemum purpureum* and *Ratibida pinnata*, germinated at higher rates when planted in the spring (April-May), still others seem to have no preference. Seeding too early in October can be detrimental, as well as planting in late June-September (Salac *et al.*, 1982). May vs. June seeding favored the former in one study (Whitney, 1983). The effects of seeding date have been studied for only a limited number of species, and not under Indiana and Indiana highway environmental conditions.

Issues of commercial seed quality are addressed elsewhere in this study. However, one issue needs to be clarified. Germination rates for many prairie and garden wildflowers have been studied only under controlled conditions (Heston, *et al.*, 1983). A handful of species have been evaluated under both controlled and field conditions. Discrepancies between the two test methods have been reported. Also, a majority of the species studied had poorer germination rates in the field than in the greenhouse (Christiansen, 1967). Germination percentages obtained in the greenhouse cannot be expected under field conditions (Heston *et al.*, 1983). Reliable field performance data of wildflower species appropriate for Indiana highways could only be obtained under conditions of direct field seeding.

2.4. Transplant Establishment of Prairie Wildflowers

2.4.1. Seedling Transplants of Prairie Species

Researchers first used prairie sod transplants to restore degraded prairie remnants, or rescue prairie areas which were to be destroyed. Successful installation of transplanted prairie sod depended upon species, environmental conditions following transplanting, and weed competition (Clements and Weaver, 1924; Curtis, 1949). Prairie perennial sod-transplants were used to establish the Curtis Prairie in Wisconsin in the 1930's, and were also used to establish sections of the Morton Arboretum's prairie. Schramm (1972) has shown that many species of prairie plants are better established as transplants rather than seed, and that transplants generally reduce establishment time of prairie plantings compared with seed establishment.

Christiansen (1967) conducted extensive research on the survival of seedling transplants in Iowa. Christiansen found that more than 90% of seedlings transplanted in the late summer or fall over-wintered. He also demonstrated that many prairie seedlings were shorter and flowered less when transplanted into *Bromus inermis* Leyss. or *Poa pratensis* L. sods compared with transplanting prairie seedlings into a tilled field. Landers, *et al.* (1970) reported nearly 100% survival of 17 prairie species transplanted on back-slopes in Iowa, but found that the establishment success of seedling transplants was dependent on weed competition and site characteristics. Nuzzo (1978) transplanted prairie perennials near highway rights-of-way using peat-containers instead of sod. She found that particular prairie species differed in survival rates and subsequent establishment when installed near highway rights-of-way. She also observed that many prairie species competed successfully with existing *Festuca arundinacea* L. sod. Finally, Nuzzo showed that seedlings of prairie forbs could be transplanted successfully on a weedy site with no impact on transplant success. Warkins and Howell (1982) successfully transplanted

seedlings of prairie forbs into an already established prairie, suggesting that forb seedlings may benefit from the protection afforded by an existing grass/forb plant community.

Curry (1980) investigated the effect of site preparation on the establishment of prairie species transplanted either in the spring or fall. She reported that site preparation with either glyphosate or bark mulch application reduced weed competition and resulted in over 80% survival of prairie seedlings.

2.4.2. Water-Holding Polymers

Water holding polymers or "hydrogels" have been available in the horticultural market in recent years. Greenhouse growers have used these compounds as soil amendments to reduce water stress in container-grown plants such as *Tagetes erecta* L. (Gehring and Lewis, 1980). Wang (1989), and Wang and Booger (1987) have reported less wilting and increased growth of tropical and foliage plants using hydrogel amendments.

Research has not always shown beneficial effects on plant growth when hydrogels are added to container mixes. Hensley (1984) reported that hydrogel amendments used as transplant aids had no benefits. Excessive fertilization may limit the water-holding capacity of some products (Wang, 1989).

Henderson and Hensley, (1990) have reported that transplants of *Lycopersicon esculentum* Mill, dipped in a hydrogel solution took longer to wilt than transplants without hydrogel amendments. They also showed that seedlings dipped in hydrogel solution grown in sand had greater leaf water potentials compared with seedlings dipped in hydrogel solution grown in finer textured soils. Thus, water-holding polymers may be a means of improving prairie transplant establishment in areas where moisture availability is very low.

2.4.3. The Effect of Container Size

Researchers have investigated the effect of container size on growth and survival of many deciduous and herbaceous species, but have not investigated the effects of transplant container size on transplantation of prairie species. Plants grown in small containers often do not grow as well as plants grown in larger containers because of limited water availability to the plants grown in the smaller containers (Spomer, 1982; Milks, *et al.*, 1989). For example, marigold seedlings grown in small containers performed poorly compared with seedlings grown in larger containers and transplanted to the field (Latimer, 1991).

Scientists first investigated the effect of container size on growth and survival of seedlings of many vegetable species. Sayre (1948) reported that early yield of tomato seedlings was greater when larger seedlings were used. Nicklow and Minges (1963) showed that tomato seedlings grown in larger containers had more leaves and faster growth rates compared with

tomato seedlings grown in smaller containers. Miller, et.al. (1969) found that seedlings of cabbage grown in larger containers formed larger heads compared with cabbage seedlings grown in smaller containers. Gorskit and Wortz (1985) reported that eggplant seedlings grown in larger containers had greater yields than eggplant seedlings grown in smaller containers.

Researchers have not always reported greater yields of vegetable crops due to increased seedling-container size. Dufault and Waters (1985) reported an increase in early growth of broccoli and cauliflower seedlings grown in larger containers compared with seedlings grown in smaller containers, but did not report an increase in yield. Csizinszky and Schuster (1993) showed that cabbage seedlings given 1.5x or 2x rates of N and K before field transplanting had similar yields regardless of container size.

Several researchers have studied the effect of seedling container size on the survival and growth of tree species. Endean and Hocking (1972) found that a greater percentage of lodgepole pine seedlings grown in larger containers survived on sites characterized by frequent drought conditions compared with seedlings grown in smaller containers. *Quercus* seedlings grown in larger volume containers grew larger in a field setting than seedlings grown in containers with less volume (Hathaway and Whitcomb, 1987). Appleton and Whitcomb (1983) found that the long-term growth of deciduous and conifer species grown in larger containers was superior to seedlings grown in smaller containers. Finally, Gilliam, *et al.* (1984) reported that seedlings of *Pyrus calleryana* 'Bradford' grown in either 38 or 57 liter containers and transplanted to a field setting were taller and had greater trunk diameters than seedlings grown in 19 liter containers. Container size is clearly an important issue in consideration of seedling transplant methodology for prairie wildflower establishment.

2.4.4. Vesicular-Arbuscular Mycorrhizae

Vesicular-arbuscular mycorrhizal (VAM) fungi are found in soils worldwide and form symbiotic relationships with plant roots, primarily aiding phosphorus uptake in host plants (Hayman, 1982). VAM were discovered on plant roots over 75 years ago (Powell and Bagyaraj, 1984), and are found on the roots of species associated with most plant families (Mosse, 1959; Nicolson, 1959). Researchers have only intensively studied VAM fungi and VAM effects on plant nutrition over the last 35 years.

Mycorrhizal symbiosis benefits the host plant in many ways. Hayman (1971) showed that onion plants associated with VAM grown in low-phosphate soil exhibited a positive growth response compared with plants not associated with VAM fungi. Mycorrhizal plants also grow taller and weigh more than non-mycorrhizal plants in stress situations such as low moisture, low fertility, and pH extremes (Maroneck, *et al.*, 1981).

VAM are adversely affected in areas subject to recent disturbance. Cuenca and Lovera (1992) reported that VA mycorrhizal propagules were reduced in disturbed sites compared to undisturbed areas. Jasper, *et al.* (1989) found that soil disturbance reduced the infectivity of certain species of VAM.

VAM inoculated seedlings have been used to re-vegetate areas characterized by disturbed soils and erosion (Harris and Jurgenson, 1977; Marx and Artman, 1979). Herrera, *et al.* (1993) showed that woody legumes inoculated with VA mycorrhizal fungi improved performance in out-planting trials in a Mediterranean desert ecosystem. Michelsen (1993), and Pope, *et al.*, (1983) reported that VAM inoculation of tree seedlings enhanced survival and growth.

Recently, researchers have investigated VAM in the context of prairie ecosystems and ecology. Most prairie grasses and forbs associate with VAM fungi (Anderson, *et al.*, 1994; Miller, 1986), possibly due to low inorganic phosphorus levels on prairie sites (Bentivenga and Hetrick, 1992). Hetrick, *et al.* (1987) have shown that warm season prairie grasses inoculated with VAM fungi grew larger than non-inoculated control plants. Zajicek, *et al.*, (1987) inoculated three species of prairie perennial forbs with VA mycorrhizal fungi. Seedlings of *Baptisia australis* L., *Liatris aspera* Michx., and *Asclepias tuberosa* L. were inoculated with four different species of VA mycorrhizal fungi. Zajicek reported that VAM-inoculated seedlings transplanted to the field were taller and flowered more compared with non-inoculated control plants after two growing seasons. Researchers at the National Wildflower Research Center investigated the effects of VA mycorrhizae inoculation on seedlings of Texas wildflowers placed in a field setting (Crank, 1991). Mycorrhizal inoculation of the seedlings resulted in taller plants with more branches than non-inoculated plants. Also, researchers have investigated the effects of fire, mowing, and fertilization on VA mycorrhizae populations in prairie ecosystems (Bentivenga and Hetrick, 1992). Hetrick, *et al.* (1989) has observed how the absence of VAM reduced the competitive dominance of *Andropogon gerardii* Vitm.

2.5. Cost Analysis

One of the goals of a highway wildflower program is the reduction of maintenance costs compared with conventional vegetation management costs. Heine (1990) reported reduced maintenance costs associated with a native grass planting at the Kansas City International Airport. Programs in Texas and Minnesota (*Better Roads*, 1990) have observed cost reductions as much as 33%. However, Guinon (1990) cautions that cost estimates for restoration and other native plant projects can vary widely and are subject to large inaccuracies.

No cost analysis has been conducted which evaluates wildflower conversion costs and long-term maintenance savings in comparison with continued conventional mowing

management. Neither have various alternatives of prairie and garden wildflowers been estimated. Lastly, no studies have attempted to predict the expected implementation costs or maintenance savings specifically for the State of Indiana Department of Transportation.

CHAPTER 3

SEED QUALITY TESTING

3.1. Problem Statement

Direct seeding techniques are often desirable for use to establish native prairie and "garden" wildflowers along highway rights-of-way. Often, companies that market wildflower seed provide their customers with little seed quality information in the form of expected seed germination percentages. Previous research on wildflower seed germination does not report germination percentages of seed obtained from commercial sources. The problem this study addressed was the concern over seed quality as a possible explanation for poor results in direct seeding of wildflowers.

3.2. Objectives

The objective of this study was to determine what level of wildflower seed quality was available from commercial sources and to compare, by type, source, and species, germination percentages of native and garden wildflower seed obtained from major seed companies using standardized laboratory testing methods. The results were desired to form the basis for INDOT to make purchase decisions or to assemble lists of acceptable suppliers.

3.3. Work Plan

Major wildflower seed supply companies were identified and seed was purchased. Eight species of "garden" wildflowers and 11 species of "native" wildflowers were evaluated. For those species with established germination test protocols (Guerke, 1988), those procedures were followed. Other species were tested using documented methods for similar species.

Eight garden wildflower species and eleven species of prairie forbs were selected for study. Garden wildflowers included: Rocket Larkspur, *Consolida ambigua* L., Plains Coreopsis, *Coreopsis tinctoria* Nutt., Common Cosmos, *Cosmos bipinnatus* Cav., Yellow Cosmos, *Cosmos sulfureus* Cav., Rocket Larkspur, California Poppy, *Eschscholtzia californica* Cham., Indian Blanket, *Gallardia pulchella* Foug, Corn Poppy, *Papaver rhoeas* L., Black-Eyed-Susan, *Rudbeckia hirta* L.

Prairie wildflowers included in this study were: Butterfly Milkweed, *Asclepias tuberosa* L., New England Aster, *Aster novae - angliae* L., Prairie Coreopsis, *Coreopsis palmata*, Pale Purple Coneflower, *Echinacea pallida* Nutt., Rattlesnake Master, *Eryngium yuccifolium* Michx., Prairie Blazing Star, *Liatris pycnostachyna* Michx., Wild Quinine, *Parthenium integrifolium* L., Large Penstemon, *Penstemon grandiflorus* Nutt., Grey - headed Coneflower, *Ratibida pinnata* Barnh., Royal Catchfly, *Silene regia* Sims., and Culver's Root, *Veronicastrum virginicum* L.

We acquired the seeds of both prairie and garden wildflowers in Oct. 1992 and in Oct. 1993 from seven seed companies which sold either garden wildflower seed, native prairie seed, or both prairie and garden wildflower seed. All seed was obtained by direct purchase in an effort to acquire representative seed of the quality which any commercial customer could expect to receive. Companies included in our study which market garden wildflower seed were: Applewood Seed Company (Arvada, Colo.), Clyde Robin Seed Company (Hayward, Calif.), and Wildseed Farms (Eagle Lake, Texas.). Companies included in our study which market prairie wildflower seed were: Prairie Moon Nursery (Winona, Min.), Prairie Nursery (Westfield, Wis.), and Prairie Ridge Nursery (Mount Horeb, Wis.).

Sharp Brothers Nursery (Clinton, Mo.) markets mostly garden wildflower seed, but also markets prairie wildflowers and grasses. However, for the purpose of these experiments, we classified Sharp Brothers as a garden wildflower seed company. We did not include any companies that offered only seed mixes. We excluded several seed companies that were unresponsive to our efforts to acquire a current sales catalog.

Standardized, documented germination test procedures do not exist for most of the species included in this study. Test conditions for undocumented species were selected based on published sources (Schulenberg, 1972), (USDA, 1993), and consultation (Dr. Larry Nees, Indiana State Seed Laboratory, personal comm.).

3.3.1. Seed Germination Procedures: Year One

The purchased seeds were stored at 4C in a seed storage facility until the experiment began in January, 1993. We randomly selected 100 seeds of each species from each company and then placed the seeds in 13.5 mm diameter plastic petri dishes containing two seed germination blotters (Anchor Paper, St. Paul, Minn.) which had been moistened with tap water (Dr. Larry Nees, Indiana State Seed Laboratory, personal comm.). Three replicates consisting of 100 seeds of each species obtained from each company were used in year one. Four replicates were used in year two of the study. During the germination phase of the experiment, petri dishes were regularly re-moistened to maintain adequate moisture level as needed. This was generally done every three days. Some unequal replication occurred in year one due to technical difficulties so that replicates of some species were reduced to two.

Garden wildflower seeds were then placed in growth chambers under fluorescent lights at 25C for 15 days, except for *Consolida ambigua* which was provided with conditions of 17C. The total number of germinated seedlings as defined by an emerged radical 2 cm long were then counted and recorded.

Seeds of most prairie species require moist-stratification before germination can occur (Schulenberg, 1972). We placed 100 seeds of each prairie species in petri dishes (as described previously for garden species) and placed the seed in a dark growth chamber at 4C for eight weeks and then transferred the seeds to a 25C lighted chamber. *Silene regia* was unlike other prairie species as its seeds did not require moist-stratification for germination. The total number of seedlings was counted after 15 days in germination conditions, in the same manner as the garden species.

3.3.2. Seed Germination Procedures: Year Two

Seed of several species from particular companies were not available due to environmental conditions that led to poor seed harvests in 1993. The acquired seed was subjected to the same storage conditions as in the previous year until the experiment began in January, 1994. We subjected the garden and prairie seeds to the same experimental conditions as in year one including the same growth chambers.

The seed germination data from both year one and year two were subjected to ANOVA using SuperAnova (Abacus Concepts, Berkeley, Calif.). Post-hoc tests of means were examined using Fischer's protected test of least significant differences.

3.4. Analysis of Data

3.4.1. Wildflower Type (Garden vs. Prairie)

Garden wildflower species had significantly ($p < .001$) higher germination percentages than prairie species. The mean across all garden species was 58% as compared with 27% for the prairie species.

3.4.2. Species Comparisons

Garden Wildflowers. *Rudbeckia hirta* seed germinated with the highest overall germination percentages (more than 70%) of the garden species. *Cosmos bipinnatus* and *Coreopsis tinctoria* also germinated at high rates (Table 3.1). *Gallardia pullchella* seed had the lowest overall germination rate of the garden wildflowers.

Prairie Wildflowers. *Ratibda pinnata* seeds germinated at the highest rates (over 50%) compared with other prairie wildflower species (Table 3.2). Several species germinated poorly. For example, less than 13% of either *Aster novae - angliae* or *Veronicastrum virginicum* seed germinated.

3.4.3. Company Comparisons

Garden Wildflower Companies. Seed obtained from Applewood Seed Company germinated at significantly higher overall combined rates ($p < .001$) compared with the three other companies that market garden wildflower seed. Seed obtained from Wildseed Farms exhibited the lowest overall germination rates in this study (Table 3.3).

Prairie Wildflower Companies. Seed obtained from Prairie Nursery germinated at significantly higher ($p < .005$) overall rates compared with seed obtained from either Prairie Moon or Prairie Ridge (Table 3.3).

3.4.4. Species/Company Comparisons

Garden Wildflowers. Germination percentages of garden wildflower seeds from different companies varied. For example, *Eschscholzia californica* seed obtained from Clyde Robin Seed germinated at a rate 15% less than seed purchased from Sharp Brothers, and 29% less than seed obtained from Applewood Seed Company (Table 3.1). *Cosmos sulphureus* seed purchased from Wildseed Farms germinated less compared with *Cosmos* seed purchased from the other companies that market garden wildflower seed (Table 3.1).

Prairie Wildflowers. Germination percentages of prairie wildflower seeds from different companies also varied. For example, *Liatris pycnostachya* seed purchased from Prairie Ridge Nursery did not germinate. However, more than 40% of *Liatris* seed purchased from Prairie Nursery germinated (Table 3.2). *Ratibda pinnata* seed purchased from Clyde Robin Seed did not germinate, while almost all of the *Ratibda* seed obtained from Prairie Nursery germinated. *Parthenium integrifolium* seed purchased from Prairie Ridge germinated at over five times the rates of seed obtained from either Prairie Nursery or Prairie Moon Nurseries. *Veronicastrum virginicum* seed acquired from Prairie Nursery had mean germination rates higher than *Veronicastrum* seed purchased from either Prairie Moon Nursery or Prairie Ridge Nursery (Table 3.2).

3.4.5. Company/Year Comparisons

Garden Wildflower Companies. The germination of seed obtained from garden wildflower companies did not vary significantly ($p > .05$) between years. However, germination

rates of seed obtained from Clyde Robin Seed appeared to indicate a difference in germination rates between years (26%, $p = .13$, Table 3.3).

Prairie Wildflower Companies. The germination of seed obtained from prairie wildflower companies varied significantly between years. The germination of seed obtained from both Prairie Ridge and Prairie Moon Nurseries varied significantly ($p < .01$) when average seed germination rates were compared on a yearly basis (Table 3.3). The germination of seed obtained from Prairie Nursery did not vary significantly from year-to-year.

3.5 Conclusions

3.5.1. Wildflower Type (Garden vs. Prairie)

It is not surprising that prairie seed germination percentages were, on average, lower than garden wildflowers. Most of the garden wildflowers in this study were annuals and are easily grown from seed compared to prairie perennial wildflowers which, much experience would suggest, are more difficult to germinate (Sperka, 1973). Prairie wildflower seed germinated at low overall rates in our study, but our observed rates are consistent with rates reported in other studies of seed from non-commercial sources (Christiansen, 1967; Voight, 1977). Blake (1935) reported that while prairie species produced large amounts of seed, only a small percentage of the seeds were viable. Also, prairie wildflower seed in this study may not have germinated at each species absolute optimum rate because uniform test conditions. Such procedures may not take into account minor differences in dormancy requirements (Blake, 1935) and optimum temperatures (Kaspar and Williams, 1982) for germination.

3.5.2. Variation Among Companies

We observed significant variation between germination rates of particular species obtained from different companies. Reasons for this variation could be due to differences in production, collection, environmental conditions in different locations during the growing season, harvesting, handling, and storage of wildflower seed. Companies that sell wildflower seed, for example, are quick to point out such differences in their individual marketing strategies

3.5.3. Variation Among Companies/Year

The quality, as measured by germination, of seed obtained from garden wildflower seed companies did not vary significantly between years. One probable reason for this lack of variation is that species of garden wildflowers have been horticulturally selected for superior traits and uniform characteristics. Also, garden wildflowers are grown and harvested in large

scale field operations, often with highly mechanized, consistent operations. They do not involve private seed collection by individuals (Cackler, et al., 1982).

We observed wide variation in prairie seed germination of particular species between companies. Two of the three companies offering prairie wildflower seed showed significant variation in seed germination rates from year-to-year. Prairie wildflower seed companies marketing strategies and production methods differ in several ways. We observed prominent differences in package label information, price, seed cleanliness (the amount of chaff present) and packaging techniques. Several companies grow prairie plants in a nursery setting, while others collect seed from the wild, and some depend on collection from private individuals to add to their seed inventory (Egan, 1994). In addition, maintenance of genetic variability (collection from many areas) is a goal of some prairie wildflower companies (Knapp and Rice, 1994). Thus, seed quality, and thus germination, could change from source to source, year to year, and company to company.

Table 3.1. Germination Percentages of Garden Wildflowers from Selected Sources.

Garden Species	Seed Company and Test Year						Total Mean Species
	Applewo d	Clyde Robin	Sharp Bros.	Wildseed	Prairie Ridge	Prairie Moon	
	93/94	93/94	93/94	93/94	93/94	93/94	
<i>Coreopsis tinctoria</i>	84.0/95.0	71.8 75.5	38.3/38.8	62.3/NA	NA/NA	NA/NA	66.5
<i>Cosmos bipinnatus</i>	75.8/84.0	67.7/44.8	75.0 /58.5	16.0/80.3	NA/NA	NA/NA	67.6
<i>Cosmos sulphureus</i>	91.8/87.0	67.3/NA	NA/NA	33.0/54.8	NA/NA	NA/NA	61.8
<i>Delphinium ajacis</i>	81.0/25.8	NA/NA	49.5/38.5	NA/48.8	NA/NA	NA/NA	40.7
<i>Eschscholtzia californica</i>	57.5/NA	28.3/NA	43.5/NA	50.8/NA	NA/NA	NA/NA	46.8
<i>Gaillardia pulchella</i>	53.3/42.0	19.8/NA	35.5/NA	25.0/19.8	NA/NA	NA/NA	33.3
<i>Papaver rhoeas</i>	74.7/79.3	32.0/76.8	57.5/56.5	67.0/21.5	NA/NA	NA/NA	59.9
<i>Rudbeckia hirta</i>	66.5/94.8	74.8/89.5	55.3/73.8	72.5/72.8	76.8/NA	82.3 NA	75.9

NA= Not available

Table 3.2: Germination Percentages of Prairie Wildflowers From Selected Sources

Prairie Species	Seed Company and Test Year					Total Mean Species
	Sharp	Wildseed	Prairie	Prairie	Prairie	
	Bros.		Nursery	Ridge	Moon	
	93/94	93/94	93/94	93/94	93/94	
<i>Asclepias tuberosa</i>	0/.8	NA/30.8	NA/NA	48.3/NA	46.3/NA	26.8
<i>Aster nova-angliae</i>	NA/NA	NA/12.5	NA/NA	8.0/0	21.3/5.8	8.9
<i>Coreopsis palmata</i>	NA/NA	NA/NA	NA/NA	25.7/34.3	NA/NA	29.4
<i>Echinacea pallida</i>	.7/NA	NA/NA	26.0/29.8	15.8/25.8	10.3/22.0	19
<i>Eryngium yuccifolium</i>	NA/NA	NA/NA	24.0/23.5	19.5/1.3	26.5/17.3	19.3
<i>Liatris pycnostachya</i>	NA/NA	NA/NA	54.3/29.5	0 / 0	20.3/31.3	22.5
<i>Parthenium</i>	NA/NA	NA/NA	17.0 / .5	59.3 / 52.8	7.5/4.0	23.5
<i>integrifolium</i>						
<i>Penstemon grandiflorus</i>	NA/NA	NA/NA	NA/73.3	54.5 / 64.3	51.3/ .75	40.6
<i>Ratibida pinnata</i>	NA / .75	NA / NA	NA / 91.3	78.3 / 10.3	42.7 / 38.3	52.3
<i>Silene regia</i>	NA/NA	NA/NA	NA/NA	NA/NA	50.3/24.3	35.4
<i>Veronicastrum</i>	NA/NA	NA/NA	NA/NA	15.8/0	17.5/2.0	13.1
<i>virginicum</i>						

NA= Not available

Table 3.3. Total Germination Percentages of Garden and Prairie Wildflowers From Selected Sources**(By Company And By Company/Year)**

Seed Company	Between Companies	Company / Year	
	Total % Germination	1993 % Germination	1994 % Germination
Applewood Seed Company	72.8 ***	73.1	72.5
Clyde Robin Seed Company	58.9	50.3	71.6
Sharp Bros. Seed Company	46.4	43.4	49.4
Wildseed Farms	45.5	48.2	42.7
Prairie Ridge Nursery	26.1	34.1	18.1**
Prairie Moon Nursery	26.3.*	33.2	17.5**
Prairie Nursery	36.9 **	30.3	39.7

Means separations are within column for Between Companies, and between columns within a row for Company/Year.

* significant at $p < .05$, ** significant at $p < .01$, *** significant at $p < .001$

CHAPTER 4

DIRECT SEEDING ESTABLISHMENT OF GARDEN AND PRAIRIE WILDFLOWERS

4.1. Problem Statement

Because no reliable information exists on the use of garden or prairie wildflowers along Indiana highways, there is a strong need to characterize appropriate species and establishment techniques for future INDOT use.

4.2. Objectives

This study was designed to evaluate selected garden and prairie wildflower species for germination and survival with minimal human assistance under the variety of conditions along Indiana highways. Test plots were established at three different highway locations, with multiple plot sites in some cases. Soil analysis was performed on samples collected at the time of plot establishment for correlation with plant performance data. Tillage, timing of seeding, and seed drilling depth were also investigated.

4.3. Work Plan

4.3.1. Spring 1993 Direct Seeding

Test plots were established at three highway locations. The locations chosen for the study were the infields of the following interchanges: **SITE 38**) I-65 and State Rd. 38 East near Dayton, IN, **SITE 52**) U.S. 52 and Northwestern Ave. in West Lafayette, IN, and **SITE 20**) U.S. 20 and Cline Ave. near Gary, IN. The sites were selected as representative examples of Indiana highway rights-of-way with good visibility and accessibility. **SITES 38** and **52** characterized typical post-construction problems which confront highway landscape architects. **SITE 38** was known to have considerable construction debris (concrete, asphalt, etc.) littering the soil surface. **SITE 52** was known to have problems with post-construction soil compaction. Both sites had been stripped of a large percentage of the topsoil originally present. **SITE 20** was chosen due to significant differences from the first two sites in regard to construction disturbances. **SITE 20** had no construction debris or compaction problems and a high percentage of the original topsoil was still present. All three sites were tested by CAL MAR Soil Testing Labs (Westerville, OH) for plant nutrient and soil texture composition:

SITE 38: Soil Texture/Nutrient Analysis

% Sand: 26 % Silt: 44 % Clay: 30 Classification: Clay Loam
 % OM: 3.0 P_I: 49 K: 296 Mg: 480 Ca: 5802 pH: 7.9
 % Base Saturations: K: 2.2 Mg: 11.8 Ca: 86 CEC: 16.9

SITE 52: Soil Texture/Nutrient Analysis

% Sand: 6 % Silt: 50 % Clay: 44 Classification: Silty Clay
 % OM: 4.8 P_I: 73 K: 396 Mg: 1102 Ca: 5777 pH: 7.9
 % Base Saturations: K: 2.6 Mg: 23.5 Ca: 74 CEC: 19.5

SITE 20: Soil Texture/Nutrient Analysis

% Sand: 70 % Silt: 10 % Clay: 20 Classification: Sandy Loam
 % OM: 2.6 P_I: 13 K: 140 Mg: 441 Ca: 5630 pH: 8.1
 % Base Saturations: K: 1.1 Mg: 11.4 Ca: 87 CEC: 16.1

Each site was prepared for seeding as follows: 1) Three weeks prior to seeding, existing vegetative cover was killed using a uniform spray application of Round-Up™ herbicide at a rate of three quarts per gallon per acre. 2) Individual species plots, 10ft(3.03m) long by 4ft(1.21m) wide, were measured and staked (separate areas were prepared for garden and prairie species). 3) A Truax Flex Drill (FLX-88) was used to create open seed furrows in each plot by disengaging the planters and press wheels and using only the six center no-till coulters. The left three coulters were set using 1/2in(1.27cm) depth bands. The right three coulters were set using 1/4in(0.64cm) depth bands.

Seeds of 12 garden wildflower species were purchased from commercial sources, primarily Applewood Seed Company. Garden wildflower species included in the Spring 1993 study were: Common Yarrow, *Achillea millefolium* L.; Cockscomb, *Celosia cristata* L.; Spider Flower, *Cleome hasslerana* Chodat; Rocket Larkspur, *Consolida ambigua* L.; Plains Coreopsis, *Coreopsis tinctoria* Nutt.; Common Cosmos, *Cosmos bipinnatus* Cav.; Yellow Cosmos, *Cosmos sulphureus* Cav.; Blanket Flower, *Gaillardia pulchella* Foug.; Dame's Rocket, *Hesperis matronalis* L.; Corn Poppy, *Papaver rhoeas* L.; Black-eyed Susan, *Rudbeckia hirta* L.; and Mealy-cup Sage, *Salvia farinacea* Benth. The garden wildflower species were selected on the basis of their aesthetic qualities, hardiness, ability to self-sow, and seasonal appeal.

Seeds of 18 prairie wildflower species were purchased from commercial sources, primarily Prairie Moon Nursery. Prairie wildflower species included in the Spring 1993 study were: Butterfly Milkweed, *Asclepias tuberosa* L.; Heath Aster, *Aster ericoides* L.; Smooth Aster, *Aster laevis* L.; New England Aster, *Aster novae-angliae* L.; Prairie Coreopsis, *Coreopsis palmata* L.; Tall Coreopsis, *Coreopsis tripteris* L.; Pale Purple Coneflower, *Echinacea pallida* (Nutt.) Nutt.; Rattlesnake Master, *Eryngium yuccifolium* Michx.; Rough Blazing Star, *Liatris aspera* Michx.; Prairie Blazing Star, *Liatris pycnostachya* Michx.; Wild Bergamot, *Monarda fistulosa* L.; Wild

Quinine, *Parthenium integrifolium* L.; Large-flowered Beardtongue, *Penstemon grandiflorus* Nutt.; Prairie Phlox, *Phlox pilosa* L.; Yellow Coneflower, *Ratibida pinnata* (Venten.) Barnh.; Royal Catchfly, *Silene regia* Sims.; Ironweed, *Vernonia fasciculata* L.; and Culver's Root, *Veronicastrum virginicum* (L.) Farw. The prairie wildflower species were selected because they are indigenous to Indiana, and because of their aesthetic qualities, range of bloom period, plant size, and hardiness.

Approximately 100 seeds of each of the species (garden and prairie) were hand-seeded into each of the appropriate seed furrows. Due to seed shortages, Cornflower, *Centaurea cyanus* L., was added to the garden wildflower species list in place of Mealy-cup Sage at **SITES 38 and 20**. Prairie Coreopsis, Prairie Phlox, and Culver's Root were eliminated from the prairie wildflower species list at **SITE 20** only. **SITE 52** was seeded on 11 May 1993, **SITE 38** was seeded on 12 May 1993, and **SITE 20** was seeded on 26 May 1993. As noted, seed counts were approximate. One hand-counted set for each species was prepared and weighed. All additional sets were prepared by weight only based on the counted sets. No additional cultural measures were applied to any of the plots for the duration of the experiment.

The individual species plots were arranged in a randomized complete block design with one replicate for each species and three blocks at each highway site. Data collection consisted of seedling/plant counts per species per 10ft(3.03m) plot including all three furrows of a given depth. Separate counts were taken for the 1/2in(1.27cm) and 1/4in(0.64cm) planting depths. Data were collected in mid-June and early August of 1993, 1994, and 1995. Data were subjected to Analysis of Variance (ANOVA).

4.3.2. Fall 1993 Direct Seeding Methods

We became concerned about the issue of seed placement and soil contact using the hand seeding into open furrows method following the spring 1993 plantings. This method was designed to emulate the seed placement achieved by drill or slit seeding machines, but with smaller plots and lower seed quantities. However, the furrows could not be closed and packed in the same way achieved by the Truax Flex Drill. A change was made so that the Truax Flex Drill would be used for all remaining plantings. As a result, plot size was increased from 10ft(3.03m) long to 30ft(9.09m) long to ensure good seed dispersal by the Truax Flex Drill. The planters and press wheels were engaged. Coulter wheels and 1/2in(1.27cm) and 1/4in(0.64cm) depth bands were used as in the spring 1993 plantings. The Truax Flex Drill was calibrated for each of the selected species to place approximately 300 seeds in each 30ft(9.09m) furrow.

Due to limited space at the U.S. 52/Northwestern Ave. location (**SITE 52**) resulting from the adoption of increased plot sizes, the seeding was moved to an alternate site. **SITES 38 and 20** remained unchanged. The replacement site (**SITE 522**) was the median strip of U.S. 52

approximately 5 mi(8km) northwest of West Lafayette, IN. **SITE 522** had similar problems with soil compaction and topsoil removal as did the original site. The alternate site was tested for plant nutrient and soil texture composition by CAL MAR Soil Testing Labs (Westerville, OH):

SITE 522: Soil Texture/Nutrient Analysis

% Sand: 34 % Silt: 42 % Clay: 24 Classification: Loam

% OM: 4 P₁: 68 K: 140 Mg: 394 Ca: 3623 pH: 7.9

% Base Saturations: K:1.6 Mg: 15.1 Ca: 83 CEC: 10.9

All plots were prepared, measured, and marked in the same manner as the Spring 1993 plots, except for the increased size. However, only the prairie species were seeded in the Fall 1993 plots. Heath Aster and Smooth Aster were eliminated and Queen-of-the-Prairie, *Filipendula rubra* (J. Hill) B. L. Robinson, was added to the species list for the Fall 1993 plantings at **SITES 522** and **38**. Due to seed shortages, Butterfly Milkweed, Heath Aster, Smooth Aster, Tall Coreopsis, Queen-of-the-Prairie, and Prairie Blazing Star all were eliminated from the species list at **SITE 20** only. **SITE 38** was seeded on 3 November 1993, **SITE 522** was seeded on 4 November 1993, and **SITE 20** was seeded on 12 November 1993. All data collection was done in the same manner as the Spring 1993 plantings. However, due to the increased plot length, a randomly selected 10ft(3.03m) length of each of the Fall 1993 plots was counted to remain consistent with data collected from the Spring 1993 plots. Data were collected in mid-June and early August of 1994 and 1995. Data were subjected to ANOVA.

4.3.3. Spring and Fall 1994 Direct Seeding Methods

The Truax Flex Drill was used for both the Spring and Fall 1994 plantings. All settings and calibrations remained unchanged. However, due to limited space, both **SITES 522 and 20** were moved to alternate highway sites. **SITE 522** was moved to the infield of the U.S. 41/U.S. 52 interchange (**SITE 4152**) approximately 5 miles Northwest of Fowler, IN. **SITE 20** was moved to the median of U.S. 41 near Beaver Ditch (**SITE 41**) approximately 5 mi(8km) south of Lake Village, IN. Neither site had problems with construction debris, soil compaction, or topsoil removal. Both alternate sites were tested for plant nutrient and soil texture composition by CAL MAR Soil Testing Labs (Westerville, OH):

SITE 4152: Soil Texture/Nutrient Analysis

% Sand: 34 % Silt: 34 % Clay: 32 Classification: Clay Loam

% OM: 5.4 P₁: 27 K: 406 Mg: 742 Ca: 3182 pH: 6.2

% Base Saturations: K:4.5 Mg: 26.6 Ca: 69 CEC: 11.6

SITE 41: Soil Texture/Nutrient Analysis

% Sand: 76 % Silt: 10 % Clay: 14 Classification: Sandy Loam
 % OM: 1.5 P₁: 72 K: 50 Mg: 257 Ca: 2424 pH: 8.0
 % Base Saturations: K:0.9 Mg: 14.9 Ca: 84 CEC: 7.2

The effects of pre-plant soil tillage on wildflower stand establishment were investigated in the Spring and Fall 1994 plantings. A tractor-mounted reverse-tine rotovator (Howard HR-10) was used to till half of each 30ft(9.09m) plot length. Tilling depth was 6in(15.24cm) for garden species and 2in(5.08cm) for prairie species. The other half of each plot was left untilled following Round-Up™ application as in previous plantings. Due to the excessively loose, sandy nature of the soil at **SITE 41**, tillage effects were investigated there only in the Spring 1994 planting.

All plots were prepared, measured, and marked in the same manner as the previous plantings. Both garden and prairie species were seeded in Spring 1994. Only the prairie species were seeded in Fall 1994. Scarlet Sage, *Salvia coccinea* Juss. ex J. Murr., was added to the species list for garden wildflowers at all sites for the Spring 1994 plantings. Heath Aster, Smooth Aster, and Queen-of-the-Prairie were eliminated from the prairie wildflower species list at all sites for both the Spring and Fall 1994 plantings. For the Spring 1994 plantings, **SITE 41** was seeded on 27 April 1994, **SITE 38** was seeded on 11 May 1994, and **SITE 4152** was seeded on 19 May 1994. For the Fall 1994 plantings, **SITE 38** was seeded on 3 November 1994, and **SITES 4152** and **41** were seeded on 10 November 1994. Data collection was done in the same manner as both the Spring and Fall 1993 plantings with the exception that separate selected 10ft(3.03m) plot counts were taken for the tilled and untilled areas. Data were collected in mid-June and early August of 1995. Data were subjected to ANOVA.

4.4. Analysis of Data

One, two, and three factor ANOVAs using SuperAnova (Abacus Concepts, Berkeley, Calif.) were performed on the plant count data to identify factors that resulted in significantly different plant numbers per plot. Significant differences are indicated by a P-value in the ANOVA Table less than .05. When factors were found to be significant, individual treatment means tables were generated for purposes of comparison of plant numbers.

In the means tables, Count is the number of plots used to generate the mean value, Mean is the average of wildflower plants per 10ft of plot, and Std. Dev. is a statistical measure of how much different one mean is from another. Small Std. Dev. suggests all the plots of that treatment were similar, large Std. Dev. means there was large variation among plots. Garden and prairie wildflowers were analyzed separately.

4.4.1. Garden Wildflower Analysis

The main effects (species, site, planting depth, year) were first analyzed to determine variables for further analysis. All data are from the early August counts of plant presence (seedling establishment) from both Spring 1993 and Spring 1994 plantings were combined and analyzed together. Table 4.1 illustrates the result.

Table 4.1: ANOVA analysis of main effects for garden wildflowers.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
SPECIES	13	743645.6	57203.5	40.1	.0001
SITE	4	183475.1	45868.8	32.1	.0001
DEPTH	1	6.3	6.3	4.4E-3	.9471
YEAR	1	9565.9	9565.9	6.7	.0100
Residual	444	634113.8	1428.2		

A significant P-value was found for species, site, and year main effects. Depth was not found to be significant. A means table was created for the species main effect (Table 4.2).

Table 4.2: Means table for species of garden wildflowers.

SPECIES	Count	Mean	Std. Dev.
COMMON COSMOS	36	154.3	93.4
YELLOW COSMOS	32	59.8	59.3
PLAINS COREOPSIS	36	26.0	37.6
ROCKET LARKSPUR	36	2.8E-2	.2
CORNFLOWER	30	30.4	37.6
SPIDER FLOWER	36	11.6	17.6
CORN POPPY	36	0.0	0.0
COCKSCOMB	36	19.4	32.3
BLACK-EYED SUSAN	36	34.0	42.8
BLANKET FLOWER	36	30.2	31.6
DAME'S ROCKET	36	7.9	10.1
COMMON YARROW	36	7.2	14.5
MEALY-CUP SAGE	24	46.4	50.7
SCARLET SAGE	18	76.4	75.2

Garden wildflower species having a mean plant presence of 25 or higher per 10'(3.03m) plot across all sites and both years were selected as being successful and worthy of consideration for use along Indiana highways. The following species from Table 4.2 meet this criteria: Common Cosmos, Yellow Cosmos, Plains Coreopsis, Cornflower, Black-Eyed Susan, Blanket Flower, Mealy-Cup Sage, and Scarlet Sage. All subsequent analyses were performed for these species only. A three factor ANOVA was generated for the three significant main effects for these species.

Table 4.3: Three factor ANOVA for species, site, and year main effects for eight selected garden wildflower species.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
SPECIES	7	482234.2	68890.6	68.7	.0001
SITE	4	299709.3	74927.3	74.8	.0001
YEAR	1	24154.3	24154.3	24.1	.0001
SPECIES * SITE	23	191098.5	8308.6	8.3	.0001
SPECIES * YEAR	5	26449.4	5289.9	5.3	.0001
SPECIES * SITE ...	0	.	.	.	.
Residual	206	206457.2	1002.2		

As illustrated in Table 4.3, the main effects and two interactions were found to have a significant P-values. A means table was generated for each main effect and interaction. The means values for species were reported in Table 4.2. The site * year interaction was not calculated because it is confounded by the use of changing specific sites during the course of the experiment necessitated by the increase in plot size.

Table 4.4: Means table for site main effect for eight selected garden wildflower species.

SITE	Count	Mean	Std. Dev.
20	36	82.6	68.2
38	84	29.0	46.7
41	48	25.2	40.9
52	36	73.3	51.7
4152	44	110.5	99.0

When mean plant presence per 10'(3.03m) sample plot is examined across all eight species and both planting years, it would appear that Site 4152 was the most favorable site for establishing the selected garden wildflowers. This is not surprising given the nature of the remnant, high quality topsoil at the site, and the relative lack of construction impact in the large infield. Sites 52 and 20 were intermediate with mean plant presence counts of 73.3 and 82.6 respectively. Sites 41 and 38 were low, with mean plant presence counts of 25.2 and 29.0 respectively. Because of significant interactions in the ANOVA, indicating each species interacts differently with each site, further analysis was done.

**Table 4.5: Means table for species and site interaction for eight selected garden
wildflower species.**

SPECIES, SITE	Count	Mean	Std. Dev.
COMMON COSMOS, 20	6	190.5	47.0
COMMON COSMOS, 38	12	97.8	68.2
COMMON COSMOS, 41	6	101.0	51.4
COMMON COSMOS, 52	6	134.5	60.8
COMMON COSMOS, 4152	6	304.5	46.0
YELLOW COSMOS, 20	6	83.5	59.2
YELLOW COSMOS, 38	12	12.0	10.0
YELLOW COSMOS, 41	6	29.2	8.5
YELLOW COSMOS, 52	6	125.8	25.0
YELLOW COSMOS, 4152	2	169.0	21.2
PLAINS COREOPSIS, 20	6	0.0	0.0
PLAINS COREOPSIS, 38	12	26.2	44.6
PLAINS COREOPSIS, 41	6	0.0	0.0
PLAINS COREOPSIS, 52	6	75.0	17.9
PLAINS COREOPSIS, 4152	6	28.8	26.2
CORNFLOWER, 20	6	33.8	25.4
CORNFLOWER, 38	12	10.7	10.7
CORNFLOWER, 41	6	7.2	7.0
CORNFLOWER, 4152	6	89.7	37.7
BLACK-EYED SUSAN, 20	6	102.0	18.6
BLACK-EYED SUSAN, 38	12	5.2	5.3
BLACK-EYED SUSAN, 41	6	1.0	1.5
BLACK-EYED SUSAN, 52	6	43.3	19.6
BLACK-EYED SUSAN, 4152	6	47.3	53.8
BLANKET FLOWER, 20	6	86.0	20.2
BLANKET FLOWER, 38	12	6.0	5.6
BLANKET FLOWER, 41	6	7.2	11.0
BLANKET FLOWER, 52	6	41.5	9.6
BLANKET FLOWER, 4152	6	34.5	19.1
MEALY-CUP SAGE, 38	6	67.0	56.4
MEALY-CUP SAGE, 41	6	15.2	19.8
MEALY-CUP SAGE, 52	6	19.7	4.1
MEALY-CUP SAGE, 4152	6	83.8	63.5
SCARLET SAGE, 38	6	23.0	21.8
SCARLET SAGE, 41	6	40.7	54.0
SCARLET SAGE, 4152	6	165.5	36.9

Site characteristics had varying effects on each of the selected species. Common Cosmos performed best at Site 4152 with 304.5 plants per sample plot, but performed very well overall at all sites with plant counts ranging from 97.8 to 190.5. Yellow Cosmos also performed best at Site 4152 with 169.0 plants per sample plot. It performed very well at Sites 20 and 52 with counts ranging from 83.5 to 125.8. It performed adequately at Site 41 with 29.2 plants per sample plot. Yellow Cosmos performed poorly at Site 38. Plains Coreopsis performed best at Site 52 with 75.0 plants per sample plot. It performed adequately at Sites 38 and 4152 with counts ranging from 26.2 to 28.8. Plains Coreopsis performed poorly at Sites 20 and 41. Cornflower performed best at Site 4152 with 89.7 plants per sample plot. It performed adequately at Site 20 with 33.8 plants. Cornflower performed poorly at Sites 38 and 41. Black-Eyed Susan and Blanket Flower performed best at Site 20 with plant counts of 102.0 and 86.0 respectively. They performed adequately at Sites 52 and 4152 with counts ranging from 34.5 to 47.3. Both species did poorly at Sites 38 and 41. Mealy-Cup Sage and Scarlet Sage performed best at 4152 with plant counts of 83.8 and 165.5 respectively. Mealy-Cup Sage performed adequately at Site 38 with 67.0 plants per sample plot. It performed poorly at Sites 41 and 52. Scarlet Sage performed adequately at both Sites 38 and 41 with counts ranging from 23.0 to 40.7 respectively. It should be noted that this particular analysis is confounded by the fact that the year main effect is not considered. Further analysis was done (Table 4.8).

Table 4.6: Means table for year main effect for eight selected garden wildflower species.

YEAR	Count	Mean	Std. Dev.
1993	108	55.4	59.7
1994	140	58.1	77.2

When mean plant presence is examined across all factors, there is no significant difference between the Spring 1993 and Spring 1994 plantings. However, because each species may interact differently with each planting year, further analysis is needed. The significance of comparing the two planting years is important when it is considered that the Spring 1994 planting incorporated tilling treatment and the Spring 1993 planting did not. There was no difference observed across all species, but some noted for individual species.

Table 4.7: Means table for species and year interaction for eight selected garden wildflower species.

SPECIES, YEAR	Count	Mean	Std. Dev.
COMMON COSMOS, 93	18	122.7	76.9
COMMON COSMOS, 94	18	185.9	99.7
YELLOW COSMOS, 93	18	72.4	61.3
YELLOW COSMOS, 94	14	43.6	54.5
PLAINS COREOPSIS, 93	18	25.0	37.6
PLAINS COREOPSIS, 94	18	27.1	38.6
CORNFLOWER, 93	12	18.5	23.6
CORNFLOWER, 94	18	38.3	43.3
BLACK-EYED SUSAN, 93	18	49.8	44.0
BLACK-EYED SUSAN, 94	18	18.3	36.3
BLANKET FLOWER, 93	18	43.7	36.8
BLANKET FLOWER, 94	18	16.7	17.9
MEALY-CUP SAGE, 93	6	19.7	4.1
MEALY-CUP SAGE, 94	18	55.3	56.0
SCARLET SAGE, 94	18	76.4	75.2

The planting year (tillage treatment) had varying effects on each of the selected species. Common Cosmos, Plains Coreopsis, Cornflower, and Mealy-Cup Sage all performed better overall in the Spring 1994 planting, when the plots were tilled pre-plant. Yellow Cosmos, Black-Eyed Susan, and Blanket Flower all performed better overall in the Spring 1993 planting, without pre-plant tillage. Scarlet Sage was planted only in the Spring of 1994; however, it is believed that this species would perform similarly to Mealy-Cup Sage. It should be noted that this particular analysis is confounded by the fact that different seed lots were used for each year (thus the variation from year to year could be due to seed viability changes and not tillage treatments) and that the site main effect is not considered. Further analysis is warranted. Table 4.8 illustrates the means table for the full interaction of the three significant main effects.

Table 4.8: Means table of full interaction between species, site, and year main effects for eight selected garden wildflower species.

SPECIES,SITE,YEAR	Count	Mean	Std. Dev.
COMMON COSMOS, 20, 93	6	190.5	47.0
COMMON COSMOS, 38, 93	6	43.2	30.4
COMMON COSMOS, 38, 94	6	152.3	46.6
COMMON COSMOS, 41, 94	6	101.0	51.4
COMMON COSMOS, 52, 93	6	134.5	60.8
COMMON COSMOS, 4152, 94	6	304.5	46.0
YELLOW COSMOS, 20, 93	6	83.5	59.2
YELLOW COSMOS, 38, 93	6	7.8	7.0
YELLOW COSMOS, 38, 94	6	16.2	11.3
YELLOW COSMOS, 41, 94	6	29.2	8.5
YELLOW COSMOS, 52, 93	6	125.8	25.0
YELLOW COSMOS, 4152, 94	2	169.0	21.2
PLAINS COREOPSIS, 20, 93	6	0.0	0.0
PLAINS COREOPSIS, 38, 93	6	0.0	0.0
PLAINS COREOPSIS, 38, 94	6	52.3	52.2
PLAINS COREOPSIS, 41, 94	6	0.0	0.0
PLAINS COREOPSIS, 52, 93	6	75.0	17.9
PLAINS COREOPSIS, 4152, 94	6	28.8	26.2
CORNFLOWER, 20, 93	6	33.8	25.4
CORNFLOWER, 38, 93	6	3.2	4.3
CORNFLOWER, 38, 94	6	18.2	9.9
CORNFLOWER, 41, 94	6	7.2	7.0
CORNFLOWER, 4152, 94	6	89.7	37.7
BLACK-EYED SUSAN, 20, 93	6	102.0	18.6
BLACK-EYED SUSAN, 38, 93	6	4.0	2.8
BLACK-EYED SUSAN, 38, 94	6	6.5	7.1
BLACK-EYED SUSAN, 41, 94	6	1.0	1.5
BLACK-EYED SUSAN, 52, 93	6	43.3	19.6
BLACK-EYED SUSAN, 4152, 94	6	47.3	53.8
BLANKET FLOWER, 20, 93	6	86.0	20.2
BLANKET FLOWER, 38, 93	6	3.5	4.8
BLANKET FLOWER, 38, 94	6	8.5	5.6
BLANKET FLOWER, 41, 94	6	7.2	11.0
BLANKET FLOWER, 52, 93	6	41.5	9.6
BLANKET FLOWER, 4152, 94	6	34.5	19.1
MEALY-CUP SAGE, 38, 94	6	67.0	56.4
MEALY-CUP SAGE, 41, 94	6	15.2	19.8
MEALY-CUP SAGE, 52, 93	6	19.7	4.1
MEALY-CUP SAGE, 4152, 94	6	83.8	63.5
SCARLET SAGE, 38, 94	6	23.0	21.8
SCARLET SAGE, 41, 94	6	40.7	54.0
SCARLET SAGE, 4152, 94	6	165.5	36.9

Table 4.8 is valuable in considering the potential effect that tillage in Spring 1994 may have had in comparison with planting without tillage in Spring 93. Site 38 is the only site having both Spring 1993 and Spring 1994 plantings at the same site. Thus it is the obvious choice for comparison of tillage effects. As noted in Chapter 3, the germination of garden wildflower seeds did not vary significantly from year to year, thus seed viability alone can not explain the significant fluctuations shown in Table 4.8. However, environmental conditions most likely played some role in the change in data values from the Spring 1993 to Spring 1994. That aside, it is striking that mean plant presence was increased dramatically in Spring 94 for 4 species and not affected for 2 species. For example, Common Cosmos had a mean plant presence of 43.2 without tillage (Spring 93) and a mean plant presence of 152.3 with tillage (Spring 94). The other species with improved presence were Yellow Cosmos, Plains Coreopsis, and Cornflower. Black-Eyed Susan and Blanket Flower showed less improved establishment. Unfortunately, neither Mealy-Cup Sage nor Scarlet Sage were replicated at Site 38.

4.4.1.1. Garden Wildflower Reseeding Analysis

Mid-June and early August seedling/plant counts were taken in 1994 to assess the reseeded success of the Spring 1993 garden wildflower plantings. A two factor ANOVA was run for the early August counts of plant presence. Mealy-Cup Sage and Scarlet Sage were not included due to late flowering performance and consequent inability to set seed. Table 4.9 illustrates this analysis.

Table 4.9: Two factor ANOVA of species and site main effects for reseeded analysis for six selected garden wildflower species.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
SPECIES	5	688232.8	137646.6	8.1	.0001
SITE	2	765722.3	382861.1	22.6	.0001
SPECIES * SITE	9	1031250.8	114583.4	6.8	.0001
Residual	34	576838.0	16965.8		

A significant P-value was achieved for each main effect and their interaction. Means tables were created for each analysis as well.

Table 4.10: Means table of species main effect for reseeding analysis for six selected garden wildflower species.

SPECIES	Count	Mean	Std. Dev.
COMMON COSMOS	9	146.6	336.2
YELLOW COSMOS	9	13.7	41.0
PLAINS COREOPSIS	9	315.3	420.4
CORNFLOWER	6	0.0	0.0
BLACK-EYED SUSAN	9	56.1	57.9
BLANKET FLOWER	9	24.3	43.1

As shown in Table 4.10, Plains Coreopsis and Common Cosmos had the greatest mean plant presence reseeding rates. Black-Eyed Susan, Blanket Flower, and Yellow Cosmos reseeded at a much lower rate. Cornflower was not successful when reseeding rates are considered. Huge variation was observed in reseeding as evidenced by the large Std.Dev. values. That is an indication that even within a plot site, success of reseeding is difficult to predict.

Table 4.11: Means table for site main effect for reseeding analysis for six selected garden wildflower species.

SITE	Count	Mean	Std. Dev.
20	18	257.5	365.8
38	18	1.9	3.0
52	15	22.3	39.6

As shown in Table 4.11, highest overall reseeding values were achieved at Site 20. Lowest overall reseeding results were achieved at Site 38.

Table 4.12: Means table of species and site interaction for reseeding analysis for six selected garden wildflower species.

SPECIES, SITE	Count	Mean	Std. Dev.
COMMON COSMOS, 20	3	430.7	520.2
COMMON COSMOS, 38	3	3.3	3.1
COMMON COSMOS, 52	3	5.7	5.5
YELLOW COSMOS, 20	3	41.0	71.0
YELLOW COSMOS, 38	3	0.0	0.0
YELLOW COSMOS, 52	3	0.0	0.0
PLAINS COREOPSIS, 20	3	870.3	75.6
PLAINS COREOPSIS, 38	3	1.0	1.7
PLAINS COREOPSIS, 52	3	74.7	65.0
CORNFLOWER, 20	3	0.0	0.0
CORNFLOWER, 38	3	0.0	0.0
BLACK-EYED SUSAN, 20	3	130.0	10.8
BLACK-EYED SUSAN, 38	3	7.0	1.7
BLACK-EYED SUSAN, 52	3	31.3	24.2
BLANKET FLOWER, 20	3	73.0	46.0
BLANKET FLOWER, 38	3	0.0	0.0
BLANKET FLOWER, 52	3	0.0	0.0

Table 4.12 simply reflects the results reported in Table 4.11. Garden wildflower reseeding rates were highest at Site 20 and lowest at Site 38 for each of the six selected species.

4.4.2. Prairie Wildflower Analysis

The data used for evaluation of plant presence of prairie wildflowers were the first growing season early August counts following Spring and Fall 1993 and 1994 sowings. These data were subjected to ANOVA analysis. The main effects for species, site, depth, year, and time are illustrated in Table 13.

Table 4.13: ANOVA analysis for main effects for prairie wildflowers

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
SPECIES	18	49947.9	2774.9	10.3	.0001
SITE	5	20088.1	4017.6	14.9	.0001
DEPTH	1	156.5	156.5	.6	.4466
YEAR	1	2875.8	2875.8	10.6	.0011
TIME	1	8408.8	8408.8	31.1	.0001
Residual	1125	303830.8	270.1		

A significant P-value was achieved for all main effects excluding seeding depth. A means table was generated for the species main effect to determine suitable species for further analysis (Table 4.14).

Table 4.14: Means table of species main effect for prairie wildflowers.

SPECIES	Count	Mean	Std. Dev.
ROYAL CATCHFLY	72	.2	.6
HEATH ASTER	18	0.0	0.0
SMOOTH ASTER	18	0.0	0.0
NEW ENGLAND ASTER	72	10.8	23.8
PRAIRIE COREOPSIS	66	.5	1.9
TALL COREOPSIS	60	2.3	5.2
PALE PURPLE CONEFLOWER	72	18.6	41.1
RATTLESNAKE MASTER	72	.6	2.4
ROUGH BLAZING STAR	72	.2	1.2
PRAIRIE BLAZING STAR	66	.7	3.6
WILD BERGAMOT	72	14.4	22.0
WILD QUININE	72	1.6	3.1
LARGE-FLOWERED BEARDTONGUE	72	3.1	9.3
PRAIRIE PHLOX	66	5.8	11.7
YELLOW CONEFLOWER	72	8.5	16.8
IRONWEED	72	14.4	16.9
CULVER'S ROOT	66	2.6	8.3
BUTTERFLY MILKWEED	63	18.5	34.4
QUEEN OF THE PRAIRIE	9	0.0	0.0

Prairie wildflower species having a mean plant presence of 8 or higher per 10'(3.03m) plot were selected as being successful and worthy of primary consideration for use along Indiana highways. The following species from Table 4.14 meet this criteria: New England Aster, Pale Purple Coneflower, Wild Bergamot, Yellow Coneflower, Ironweed, and Butterfly Milkweed. All subsequent analysis was done for these 6 species only. Means tables were generated for each of the significant main effects excluding species which was reported in Table 4.14.

Table 4.15: Means table for site main effect for six selected prairie wildflower species.

SITE	Count	Mean	Std. Dev.
20	66	25.5	29.1
38	141	12.6	31.8
41	72	4.3	9.7
52	36	35.3	36.4
522	36	15.9	22.2
4152	72	4.9	11.1

When overall mean plant presence is considered across all factors, Sites 52 and 20 appear to have been the most successful sites for prairie wildflower establishment. Sites 522 and 38 were intermediate and Sites 4152 and 41 were poor for establishing prairie wildflowers.

Table 4.16: Means table of year main effect for six selected prairie wildflower species.

YEAR	Count	Mean	Std. Dev.
1993	207	19.0	27.1
1994	216	9.4	26.7

There appears to have been a trend toward difference between the 1993 and 1994 plantings. In Chapter 3 it was noted that the viability and subsequent germination of prairie wildflowers can fluctuate significantly from year to year based exclusively on seed quality. Environmental conditions likely also have had an effect on these data.

Table 4.17: Means table for timing of seed sowing (Spring vs. Fall) main effect for six selected prairie wildflower species.

TIMING	Count	Mean	Std. Dev.
SPRING	216	10.9	23.7
FALL	207	17.5	30.2

There appears to be a weak trend toward greater success of Fall plantings across all species, but not a statistically significant one. Further analysis was done.

Table 4.18: Means table of combined timing and year main effect for six selected prairie wildflower species.

TIME/YEAR	Count	Mean	Std. Dev.
FALL/93	99	16.2	23.3
FALL/94	108	18.6	35.4
SPRING/93	108	21.5	30.0
SPRING/94	108	.3	1.9

Overall, the Spring 1993 plantings appear to have been the most successful, though not significantly so. Fall 1993 and Fall 1994 plantings were consistent and the Spring 1994 planting appears to have done very poorly.

Table 4.19: ANOVA analysis of species main effect interactions with year, time, and time/year main effects for six selected prairie wildflower species.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
SPECIES	4	18903.0	4725.7	8.5	.0001
SITE	1	2275.0	2275.0	4.1	.0434
YEAR	1	7544.2	7544.2	13.6	.0003
TIME	1	6031.4	6031.4	10.9	.0011
SPECIES * SITE	5	17345.3	3469.1	6.3	.0001
SPECIES * YEAR	5	26799.9	5360.0	9.7	.0001
SPECIES * TIME	5	20066.4	4013.3	7.2	.0001
Residual	387	214482.2	554.2		

A significant P-value was achieved for each of the interactions. As a result, all subsequent means tables were generated.

Table 4.20: Means table of species and site interaction for six selected prairie wildflower species.

SPECIES, SITE	Count	Mean	Std. Dev.
NEW ENGLAND ASTER, 20	12	0.0	0.0
NEW ENGLAND ASTER, 38	24	15.2	30.5
NEW ENGLAND ASTER, 41	12	.6	1.4
NEW ENGLAND ASTER, 52	6	0.0	0.0
NEW ENGLAND ASTER, 522	6	48.0	31.0
NEW ENGLAND ASTER, 4152	12	10.0	12.9
PALE PURPLE CONEFLOWER, 20	12	26.3	26.5
PALE PURPLE CONEFLOWER, 38	24	28.3	65.4
PALE PURPLE CONEFLOWER, 41	12	12.8	18.0
PALE PURPLE CONEFLOWER, 52	6	1.7	1.5
PALE PURPLE CONEFLOWER, 522	6	27.0	15.5
PALE PURPLE CONEFLOWER, 4152	12	1.4	2.4
WILD BERGAMOT, 20	12	38.2	25.4
WILD BERGAMOT, 38	24	4.8	9.9
WILD BERGAMOT, 41	12	5.8	9.9
WILD BERGAMOT, 52	6	48.2	11.2
WILD BERGAMOT, 522	6	0.0	0.0
WILD BERGAMOT, 4152	12	8.9	21.3
YELLOW CONEFLOWER, 20	12	11.1	13.1
YELLOW CONEFLOWER, 38	24	5.1	9.8
YELLOW CONEFLOWER, 41	12	1.2	2.1
YELLOW CONEFLOWER, 52	6	38.0	41.7
YELLOW CONEFLOWER, 522	6	11.2	8.4
YELLOW CONEFLOWER, 4152	12	3.7	5.4
IRONWEED, 20	12	35.2	19.4
IRONWEED, 38	24	11.4	10.2
IRONWEED, 41	12	0.0	0.0
IRONWEED, 52	6	37.2	9.7
IRONWEED, 522	6	9.0	9.4
IRONWEED, 4152	12	5.4	7.1
BUTTERFLY MILKWEED, 20	6	59.2	52.7
BUTTERFLY MILKWEED, 38	21	10.8	17.4
BUTTERFLY MILKWEED, 41	12	5.2	7.4
BUTTERFLY MILKWEED, 52	6	86.8	32.3
BUTTERFLY MILKWEED, 522	6	0.0	0.0
BUTTERFLY MILKWEED, 4152	12	0.0	0.0

Site characteristics had varying effects on each of the selected species. New England Aster performed best at Site 522 with 48.0 plants per sample plot. It performed adequately at Sites 4152 and 38 with counts ranging from 10.0 to 15.2. New England Aster performed poorly at Sites 20, 41, and 52. Pale Purple Coneflower performed best at Site 38 with 28.3 plants per sample plot. It performed consistently at Sites 20 and 522 with counts ranging from 26.3 to 27.0. It performed adequately at Site 41 with 12.8 plants per sample plot. Pale Purple Coneflower performed poorly at Sites 52 and 4152. Wild Bergamot performed best at Site 52 with 48.2 plants per sample plot. It performed well at Site 20 with 38.2 plants and adequately at Site 4152 with 8.9 plants. Wild Bergamot performed poorly at Sites 522, 41, and 38. Yellow Coneflower also performed best at Site 52 with 38.0 plants per sample plot. It performed consistently at Sites 20 and 522 with counts ranging of 11.1 and 11.2 respectively. Yellow Coneflower performed poorly at Sites 38, 41, and 4152. Ironweed performed best at Site 52 with 37.2 plants. It performed very well at Site 20 with 35.2 plants and adequately at Sites 522 and 38 with counts ranging from 9.0 to 11.4. Ironweed performed poorly at Sites 4152 and 41. Butterfly milkweed also performed best at 52 with 86.8 plants per sample plot (the best performance for any species at any site). It performed well at Site 20 with 59.2 plants per sample plot. It performed adequately at Site 38 with 10.8 plants and poorly at Sites 41, 522, 4152. It should be noted that this particular analysis is confounded by the fact that the other factors are not considered. Further analysis is warranted.

Table 4.21: Means table for species and year interaction for six selected prairie wildflower species.

SPECIES, YEAR	Count	Mean	Std. Dev.
NEW ENGLAND ASTER, 93	36	8.0	21.6
NEW ENGLAND ASTER, 94	36	13.6	25.8
PALE PURPLE CONEFLOWER, 93	36	15.8	20.1
PALE PURPLE CONEFLOWER, 94	36	21.4	54.8
WILD BERGAMOT, 93	36	22.1	25.3
WILD BERGAMOT, 94	36	6.8	14.8
YELLOW CONEFLOWER, 93	36	12.7	21.6
YELLOW CONEFLOWER, 94	36	4.2	8.5
IRONWEED, 93	36	22.9	18.7
IRONWEED, 94	36	5.9	8.8
BUTTERFLY MILKWEED, 93	27	36.8	45.6
BUTTERFLY MILKWEED, 94	36	4.7	9.8

As shown in Table 4.21, all species with the exception of New England Aster and Pale Purple Coneflower, performed better in the 1993 plantings.

Table 4.22: Means table for species and timing interaction for six selected prairie wildflower species.

SPECIES, TIMING	Count	Mean	Std. Dev.
NEW ENGLAND ASTER, S	36	0.0	0.0
NEW ENGLAND ASTER, F	36	21.7	30.1
PALE PURPLE CONEFLOWER, S	36	1.8	5.5
PALE PURPLE CONEFLOWER, F	36	35.3	53.1
WILD BERGAMOT, S	36	12.1	18.6
WILD BERGAMOT, F	36	16.8	25.0
YELLOW CONEFLOWER, S	36	9.6	22.0
YELLOW CONEFLOWER, F	36	7.4	9.3
IRONWEED, S	36	14.2	17.1
IRONWEED, F	36	14.7	16.9
BUTTERFLY MILKWEED, S	36	27.6	42.5
BUTTERFLY MILKWEED, F	27	6.3	10.9

As shown in Table 4.22, timing of seeding had a varying effect on the selected species. New England Aster and Pale Purple Coneflower performed better when seeded in the Fall plantings. Wild Bergamot, Yellow Coneflower, and Ironweed appear to have no specific preference. Butterfly Milkweed performed better when planted in the Spring plantings.

Table 4.23: Means table for species and time/year interaction for six selected prairie wildflower species.

SPECIES, TIME/YEAR	Count	Mean	Std. Dev.
NEW ENGLAND ASTER, FALL/93	18	16.1	28.7
NEW ENGLAND ASTER, FALL/94	18	27.3	31.2
NEW ENGLAND ASTER, SPRING/93	18	0.0	0.0
NEW ENGLAND ASTER, SPRING/94	18	0.0	0.0
PALE PURPLE CONEFLOWER, FALL/93	18	27.9	21.6
PALE PURPLE CONEFLOWER, FALL/94	18	42.8	72.2
PALE PURPLE CONEFLOWER, SPRING/93	18	3.7	7.4
PALE PURPLE CONEFLOWER, SPRING/94	18	0.0	0.0
WILD BERGAMOT, FALL/93	18	19.9	30.2
WILD BERGAMOT, FALL/94	18	13.6	18.9
WILD BERGAMOT, SPRING/93	18	24.2	20.0
WILD BERGAMOT, SPRING/94	18	0.0	0.0
YELLOW CONEFLOWER, FALL/93	18	6.3	8.1
YELLOW CONEFLOWER, FALL/94	18	8.4	10.5
YELLOW CONEFLOWER, SPRING/93	18	19.1	28.4
YELLOW CONEFLOWER, SPRING/94	18	0.0	0.0
IRONWEED, FALL/93	18	19.1	21.2
IRONWEED, FALL/94	18	10.3	9.9
IRONWEED, SPRING/93	18	26.8	15.6
IRONWEED, SPRING/94	18	1.6	4.4
BUTTERFLY MILKWEED, FALL/93	9	0.0	0.0
BUTTERFLY MILKWEED, FALL/94	18	9.4	12.2
BUTTERFLY MILKWEED, SPRING/93	18	55.2	45.9
BUTTERFLY MILKWEED, SPRING/94	18	0.0	0.0

Table 4.23 illustrates a closer look at the timing of seeding and year main effects combined. The conclusions that can be drawn from this table are the same as those note for Table 4.22; However, an in depth look at where the mean plant presence values fall is of some interest. For example, in Table 22, Butterfly Milkweed appears to perform better when seeded in the Spring. In Table 23, we can see that mean plant presence falls almost exclusively within the Spring 1993 plantings with poor performance in the Spring 1994 plantings. Fluctuation of seed germination as reported in Chapter 3 may account for this discrepancy. A more accurate analysis for the prairie wildflower seeding data is illustrated in Table 4.24. ANOVA analysis of the full interaction between species, site, and time/year main effects was generated.

Table 4.24: ANOVA analysis of full interaction between species, site, and time/year main effects for six selected prairie wildflower species.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
SPECIES * SITE * TIME/YEAR	70	188747.9	2696.4	7.6	.0001
Residual	352	124933.8	354.9		

This analysis produced a significant P-value and thus a means table was generated (Table 4.25).

**Table 4.25: Means table of full interaction between species, site, and time/year
main effects for six selected prairie wildflower species.**

SPECIES, SITE, TIME/YEAR	Count	Mean	Std. Dev.
NEW ENGLAND ASTER, 20, FALL/93	6	0.0	0.0
NEW ENGLAND ASTER, 20, SPRING/93	6	0.0	0.0
NEW ENGLAND ASTER, 38, FALL/93	6	.2	.4
NEW ENGLAND ASTER, 38, FALL/94	6	60.7	31.1
NEW ENGLAND ASTER, 38, SPRING/93	6	0.0	0.0
NEW ENGLAND ASTER, 38, SPRING/94	6	0.0	0.0
NEW ENGLAND ASTER, 41, FALL/94	6	1.2	1.8
NEW ENGLAND ASTER, 41, SPRING/94	6	0.0	0.0
NEW ENGLAND ASTER, 52, SPRING/93	6	0.0	0.0
NEW ENGLAND ASTER, 522, FALL/93	6	48.0	31.0
NEW ENGLAND ASTER, 4152, FALL/94	6	20.0	11.2
NEW ENGLAND ASTER, 4152, SPRING/94	6	0.0	0.0
PALE PURPLE CONEFLOWER, 20, FALL/93	6	44.5	24.5
PALE PURPLE CONEFLOWER, 20, SPRING/93	6	8.2	12.2
PALE PURPLE CONEFLOWER, 38, FALL/93	6	12.2	10.9
PALE PURPLE CONEFLOWER, 38, FALL/94	6	99.8	106.0
PALE PURPLE CONEFLOWER, 38, SPRING/93	6	1.2	.4
PALE PURPLE CONEFLOWER, 38, SPRING/94	6	0.0	0.0
PALE PURPLE CONEFLOWER, 41, FALL/94	6	25.7	17.9
PALE PURPLE CONEFLOWER, 41, SPRING/94	6	0.0	0.0
PALE PURPLE CONEFLOWER, 52, SPRING/93	6	1.7	1.5
PALE PURPLE CONEFLOWER, 522, FALL/93	6	27.0	15.5
PALE PURPLE CONEFLOWER, 4152, FALL/94	6	2.8	2.7
PALE PURPLE CONEFLOWER, 4152, SPRING/94	6	0.0	0.0
WILD BERGAMOT, 20, FALL/93	6	59.8	15.4
WILD BERGAMOT, 20, SPRING/93	6	16.5	7.3
WILD BERGAMOT, 38, FALL/93	6	0.0	0.0
WILD BERGAMOT, 38, FALL/94	6	11.2	15.4
WILD BERGAMOT, 38, SPRING/93	6	8.0	10.0
WILD BERGAMOT, 38, SPRING/94	6	0.0	0.0
WILD BERGAMOT, 41, FALL/94	6	11.7	11.5
WILD BERGAMOT, 41, SPRING/94	6	0.0	0.0
WILD BERGAMOT, 52, SPRING/93	6	48.2	11.2
WILD BERGAMOT, 522, FALL/93	6	0.0	0.0
WILD BERGAMOT, 4152, FALL/94	6	17.8	28.4
WILD BERGAMOT, 4152, SPRING/94	6	0.0	0.0

YELLOW CONEFLOWER, 20, FALL/93	6	7.7	8.5
YELLOW CONEFLOWER, 20, SPRING/93	6	14.5	16.6
YELLOW CONEFLOWER, 38, FALL/93	6	0.0	0.0
YELLOW CONEFLOWER, 38, FALL/94	6	15.5	15.3
YELLOW CONEFLOWER, 38, SPRING/93	6	4.8	4.4
YELLOW CONEFLOWER, 38, SPRING/94	6	0.0	0.0
YELLOW CONEFLOWER, 41, FALL/94	6	2.5	2.4
YELLOW CONEFLOWER, 41, SPRING/94	6	0.0	0.0
YELLOW CONEFLOWER, 52, SPRING/93	6	38.0	41.7
YELLOW CONEFLOWER, 522, FALL/93	6	11.2	8.4
YELLOW CONEFLOWER, 4152, FALL/94	6	7.3	5.7
YELLOW CONEFLOWER, 4152, SPRING/94	6	0.0	0.0
IRONWEED, 20, FALL/93	6	36.3	26.3
IRONWEED, 20, SPRING/93	6	34.2	11.6
IRONWEED, 38, FALL/93	6	12.0	14.3
IRONWEED, 38, FALL/94	6	20.0	7.2
IRONWEED, 38, SPRING/93	6	9.0	4.6
IRONWEED, 38, SPRING/94	6	4.7	7.0
IRONWEED, 41, FALL/94	6	0.0	0.0
IRONWEED, 41, SPRING/94	6	0.0	0.0
IRONWEED, 52, SPRING/93	6	37.2	9.7
IRONWEED, 522, FALL/93	6	9.0	9.4
IRONWEED, 4152, FALL/94	6	10.8	6.4
IRONWEED, 4152, SPRING/94	6	0.0	0.0
BUTTERFLY MILKWEED, 20, SPRING/93	6	59.2	52.7
BUTTERFLY MILKWEED, 38, FALL/93	3	0.0	0.0
BUTTERFLY MILKWEED, 38, FALL/94	6	18.0	16.0
BUTTERFLY MILKWEED, 38, SPRING/93	6	19.7	24.3
BUTTERFLY MILKWEED, 38, SPRING/94	6	0.0	0.0
BUTTERFLY MILKWEED, 41, FALL/94	6	10.3	7.6
BUTTERFLY MILKWEED, 41, SPRING/94	6	0.0	0.0
BUTTERFLY MILKWEED, 52, SPRING/93	6	86.8	32.3
BUTTERFLY MILKWEED, 522, FALL/93	6	0.0	0.0
BUTTERFLY MILKWEED, 4152, FALL/94	6	0.0	0.0
BUTTERFLY MILKWEED, 4152, SPRING/94	6	0.0	0.0

The data presented in Table 4.25 gives a good summary of overall plant performance for the six selected species and a summary table is included in the conclusions section of this particular study (Table 4.31).

4.4.2.1. Prairie Wildflower Tillage Analysis

Tillage treatment was added to the Spring and Fall 1994 plantings. Thus, ANOVA analysis was generated for the early August counts of plant presence for the Spring and Fall 1994 plantings only to determine the effects of tillage. Table 4.26 illustrates this analysis.

Table 4.26: ANOVA analysis of tillage main effects for six selected prairie wildflower species.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
"TILL(Y/N)"	1	5546.8	5546.8	2.2	.1393
SPECIES * "TILL(Y/N)"	10	79010.2	7901.0	3.1	.0008
SPECIES * "TILL(Y/N)" * SITE	24	123826.1	5159.4	2.0	.0031
Residual	360	909773.2	2527.1		

Tillage across all species was not significant, but a significant P-value was achieved for the interactions of tillage and species and site. Thus, means tables were generated.

Table 4.27: Means table of tillage main effect for six selected prairie wildflower species.

	Count	Mean	Std. Dev.
TILL yes	180	20.6	74.8
TILL no	216	9.4	26.7

It is clear that in these data, tillage was not a consistently beneficial or detrimental practice. The variation, as indicated by the Std. Dev. is too great. However, tillage is confounded by Spring vs. Fall plantings, and different seed lots (as noted in Chapter 3 there was significant fluctuation in prairie seed germination from year to year). Further analysis is warranted.

Table 4.28: Means table for species and tillage interaction for six selected prairie wildflower species.

SPECIES, TILLAGE(y/n)	Count	Mean	Std. Dev.
NEW ENGLAND ASTER, yes	30	15.6	28.4
NEW ENGLAND ASTER, no	36	13.6	25.8
PALE PURPLE CONEFLOWER, yes	30	75.6	169.8
PALE PURPLE CONEFLOWER, no	36	21.4	54.8
WILD BERGAMOT, yes	30	14.0	17.8
WILD BERGAMOT, no	36	6.8	14.8
YELLOW CONEFLOWER, yes	30	1.2	1.7
YELLOW CONEFLOWER, no	36	4.2	8.5
IRONWEED, yes	30	11.6	23.2
IRONWEED, no	36	5.9	8.8
BUTTERFLY MILKWEED, yes	30	5.5	12.6
BUTTERFLY MILKWEED, no	36	4.7	9.8

As shown in Table 4.28, Pale Purple Coneflower, Wild Bergamot, and Ironweed appear to establish better with tillage. Yellow Coneflower germination appears to have been hindered by tillage. The issue of tillage may be site specific, thus, further analysis is warranted.

Table 4.29: Means table of species, tillage, and site interaction for six selected species of prairie wildflowers.

SPECIES, TILLAGE(y/n), SITE	Count	Mean	Std. Dev.
NEW ENGLAND ASTER, yes, 38	12	25.4	37.6
NEW ENGLAND ASTER, yes, 41	6	0.0	0.0
NEW ENGLAND ASTER, yes, 4152	12	13.7	21.6
NEW ENGLAND ASTER, no, 38	12	30.3	38.0
NEW ENGLAND ASTER, no, 41	12	.6	1.4
NEW ENGLAND ASTER, no, 4152	12	10.0	12.9
PALE PURPLE CONEFLOWER, yes, 38	12	140.7	253.2
PALE PURPLE CONEFLOWER, yes, 41	6	0.0	0.0
PALE PURPLE CONEFLOWER, yes, 4152	12	48.3	57.8
PALE PURPLE CONEFLOWER, no, 38	12	49.9	88.5
PALE PURPLE CONEFLOWER, no, 41	12	12.8	18.0
PALE PURPLE CONEFLOWER, no, 4152	12	1.4	2.4
WILD BERGAMOT, yes, 38	12	22.9	16.0
WILD BERGAMOT, yes, 41	6	0.0	0.0
WILD BERGAMOT, yes, 4152	12	12.2	19.5
WILD BERGAMOT, no, 38	12	5.6	11.9
WILD BERGAMOT, no, 41	12	5.8	9.9
WILD BERGAMOT, no, 4152	12	8.9	21.3
YELLOW CONEFLOWER, yes, 38	12	1.8	1.9
YELLOW CONEFLOWER, yes, 41	6	0.0	0.0
YELLOW CONEFLOWER, yes, 4152	12	1.1	1.7
YELLOW CONEFLOWER, no, 38	12	7.8	13.1
YELLOW CONEFLOWER, no, 41	12	1.2	2.1
YELLOW CONEFLOWER, no, 4152	12	3.7	5.4
IRONWEED, yes, 38	12	13.6	25.6
IRONWEED, yes, 41	6	0.0	0.0
IRONWEED, yes, 4152	12	15.4	26.0
IRONWEED, no, 38	12	12.3	10.5
IRONWEED, no, 41	12	0.0	0.0
IRONWEED, no, 4152	12	5.4	7.1
BUTTERFLY MILKWEED, yes, 38	12	13.2	17.6
BUTTERFLY MILKWEED, yes, 41	6	1.0	2.4
BUTTERFLY MILKWEED, yes, 4152	12	0.0	0.0
BUTTERFLY MILKWEED, no, 38	12	9.0	14.3
BUTTERFLY MILKWEED, no, 41	12	5.2	7.4
BUTTERFLY MILKWEED, no, 4152	12	0.0	0.0

Table 4.29 looks at tillage effects per species at each site. The following species followed the same basic trend: New England Aster, Pale Purple Coneflower, and Wild Bergamot. These species appear to have preferred tillage at Sites 38 and 4152, but were hindered by tillage at Site 41 (likely due to the loose sandy texture of the soil). Yellow Coneflower was hindered by tillage at all sites. Ironweed preferred tillage at Site 4152 was unaffected by tillage at Sites 41 and 38. Butterfly Milkweed preferred tillage at Site 38 and was unaffected by tillage at Site 4152. It appeared to be hindered by tillage at Site 41 (again probably due to the high percentage of sand in the soil).

4.5. Conclusions

4.5.1. Garden Wildflowers

There were significant differences in the performance of the 14 garden wildflower species evaluated in this study. Eight species were selected for primary use along Indiana highways: Common Cosmos, Yellow Cosmos, Plains Coreopsis, Cornflower, Black-Eyed Susan, Blanket Flower, Mealy-Cup Sage, and Scarlet Sage. These 8 species performed differently at each of the selected highway sites and at each of the planting dates. A summary of the establishment and reseeding success for each of these species is presented in Table 13. Seeding depth [1/2"(1.27cm) vs. 1/4"(0.64cm)] was not a significant issue. Tillage was an inconclusive issue deserving of further study.

Table 4.30: Summary of establishment and reseeding performance for eight selected garden wildflower species.

Species	Site/Year						Reseeding	
	20/93	38/93	38/94	41/94	52/93	4152/94	Rate	Comments
Common Cosmos	2	6	3	5	4	1	high	most successful species at all sites, strong reseeders
Yellow Cosmos	3	6	5	4	2	1	low	good performer overall
Plains Coreopsis	4	4	2	4	1	3	high	strong reseeders

Cornflower	2	5	3	4	NA	1	low	good performer on better soils, poor reseeder
Black-Eyed Susan	1	5	4	6	3	2	low	slow reseeder but may proliferate long term due to annual/perennial nature
Blanket Flower	1	6	4	5	2	3	low	variable performer, slow to establish
Mealy-Cup Sage	NA	NA	2	4	3	1	NA	late flowering, slow to establish
Scarlet Sage	NA	NA	3	2	NA	1	NA	late flowering, slow to establish

KEY: 1= highest ranked establishment performance

6= lowest ranked establishment performance

4.5.2. Prairie Wildflowers

There were significant differences in the performance of the 19 prairie wildflower species evaluated in this study. Six species were identified for primary use along Indiana highways: New England Aster, Pale Purple Coneflower, Wild Bergamot, Yellow Coneflower, Ironweed, and Butterfly Milkweed. These 6 species performed differently at each of the selected highway sites and at each of the planting dates. A summary of the establishment success for each of these species is reported in Table 4.31. Seeding depth [1/2"(1.27cm) vs. 1/4"(0.64cm)] was not a significant issue. Tillage was an inconclusive or unresolved issue deserving of further study.

Table 4.31: Summary of establishment and performance for six selected prairie wildflower species.

Species	Site	Timing	Year	Mean Plant Presence	Comments
New England Aster	38	Fall	1994	60.7	best planted in Fall,
	522	Fall	1994	48.0	late bloomer,
	4152	Fall	1994	20.0	good visual impact
Pale Purple Coneflower	20	Fall	1993	44.5	best planted in Fall,
	20	Spring	1993	8.2	late Spring bloomer,
	38	Fall	1993	12.2	best planted in masses
	38	Fall	1994	99.8	
	41	Fall	1994	25.7	
	522	Fall	1993	27.0	
Wild Bergamot	20	Fall	1993	59.8	no strong timing preference,
	20	Spring	1993	16.5	mid-summer bloomer,
	38	Fall	1994	11.2	good visual impact when
	38	Spring	1993	8.0	planted with Yellow Coneflower
	41	Fall	1994	11.7	
	52	Spring	1993	48.2	
	4152	Fall	1994	17.8	
Yellow Coneflower	20	Spring	1993	14.5	no strong timing preference,
	38	Fall	1994	15.5	mid-summer bloomer,
	52	Spring	1993	38.0	good visual impact when
	522	Fall	1993	11.2	planted with Wild Bergamot

Ironweed	20	Fall	1993	36.3	no strong timing preference, late bloomer
	20	Spring	1993	34.2	
	38	Fall	1993	12.0	
	38	Fall	1994	20.0	
	38	Spring	1993	9.0	
	52	Spring	1993	37.2	
	522	Fall	1993	9.0	
	4152	Fall	1994	10.8	
Butterfly Milkweed	20	Spring	1993	59.2	best planted in Spring, summer bloomer, small stature may present visibility problem
	38	Fall	1994	18.0	
	38	Spring	1993	19.7	
	41	Fall	1994	10.3	
	52	Spring	1993	86.8	

CHAPTER 5

TRANSPLANT ESTABLISHMENT OF PRAIRIE WILDFLOWERS

5.1. Problem Statement

The use of native prairie wildflowers along Midwestern highway rights-of-way has increased since 1980 in response to changing public attitudes towards environmentalism and federal mandates which require minimum wildflower use on highway landscape projects (Harrington, 1994). In the Midwest, prairie wildflowers appear to meet the criteria of erosion control, aesthetics, low maintenance, and cost effectiveness that are considered essential for a successful roadside vegetation planting (Weaver, 1954; Morrison, 1981).

Restorationists often use direct seeding techniques to install prairie wildflower plantings (Schramm, 1978). However, state highway department personnel in Illinois and Wisconsin have used seedling transplants to establish prairie species along highways (Nuzzo, 1975).

The seedling-transplant method of prairie plant installation offers some advantages compared with direct seeding methods. Seed of prairie species is expensive and germination percentages of prairie seed are low. Seedling installation on restoration projects may be more cost effective compared with the direct seeding method. Seedlings of prairie species are also quicker to establish and compete more effectively with weeds than plants installed by direct seeding methods (Schulenberg, 1972). Finally, seedlings of prairie forbs have been installed in prairie restorations in which direct seeding techniques have resulted in low species diversity (Warkins and Howell, 1982).

Individuals who establish native prairie species on particular restoration sites have relied on information from wildflower seed companies, state highway reports, and trial and error experiments to make decisions regarding site preparation, weed control, planting dates and procedures, and species selection for a particular restoration site. For example, most companies that market wildflower seeds or plants recommend Round-up (glyphosate) application on a site to eliminate existing weeds (Diboll, 1994). Smith and Smith (1982) recommend spring or late summer installation of seedling transplants of prairie wildflowers. Additional information about prairie seedling installation along highways based on quantitative observations would assist INDOT roadside managers and other individuals involved in prairie plant establishment to make better decisions regarding plant material selection and methods for the installation of prairie seedlings along highway rights-of-way.

5.2. Objectives

The objectives of this study were to evaluate several aspects of site preparation and installation techniques concerning their effect on survival and growth of prairie perennial seedlings. The questions we wished to answer were:

1. Does prairie seedling installation on a highway site a) pre-treated with non-selective, non-residual herbicide (glyphosate), b) mowed *Festuca arundinacea* Schreb., or c) a constructed prairie, result in prairie seedling growth and survival differences? (Section 5.3 & 5.4)
2. Does the timing of seedling installation affect growth and survival of the prairie seedlings? (Section 5.4)
3. Does hydrogel amendment to prairie perennial seedling growing media affect growth and survival of prairie transplants planted on a steep right-of-way bank? (Section 5.5)
4. Does vesicular-arbuscular mycorrhizal (VAM) inoculation of prairie seedlings during the production phase result in increased growth and higher survival rates when the seedlings are planted on highway sites? (Section 5.6)

5.3. Site Preparation Study

(Site Preparation by Mowing or Glyphosate Application affects Height and Shoot Number of Prairie Wildflower Seedlings Installed on an Indiana Highway Right-of-way)

5.3.1. Literature Review and Specific Study Objective

Site pre-treatment with Round-up herbicide (glyphosate) is often recommended as a method to rid a particular site of all vegetative cover before installing a wildflower planting (Diboll, 1994). However, no quantitative research exists to support this recommendation. In fact, Christiansen (1967) found that transplants of many prairie species such as *Ratibida pinnata* (Venten.) Barnh. competed well with weed species and cover crops. Nuzzo (1978) reported that particular prairie species were protected from harsh conditions near a Wisconsin highway by existing cover. The objective of this study was to determine if site preparation either by pre-treating the site with glyphosate or mowing the existing vegetation on an Indiana highway right-of-way would affect survival and growth of two native prairie species.

5.3.2. Work Plan

Seeds of *Ratibida pinnata* and *Andropogon gerardii* Vitm. were obtained from Prairie Ridge Nursery (Mt. Horeb, Wis.) in Oct., 1992. *Ratibida pinnata* was selected because it is a common constituent species of Indiana prairie remnants. *Andropogon gerardii* was chosen

because it is a dominant grass species on mesic prairie remnant sites in Indiana. In addition, a comparison between a grass and a forb species was sought.

The seed of both species was stored at 4C until the experiment began in May, 1993. We then filled seedling trays with a steam-pasteurized (80C) mix containing 2:2:1 (v/v/v) ratio of perlite, sphagnum peat moss and soil amended with 890 g Ca (H₂PO₄)₂, 593 g KNO₃, 593 g MgSO₄, 4.75 kg ground limestone and 74.2 Peters fritted trace elements No. 555, all per cubic meter of mix. We placed the forb and grass seed on top of the mix in the seedling trays, and placed the trays under intermittent mist for 10 days until the seeds germinated. The trays containing the emerging seedlings were then transferred to a greenhouse bench where they were watered daily. The plants were fertilized at each watering with 201 mg L⁻¹ N: this was supplied from KNO₃, Ca (NO₃)₂, and NH₄NO₃ at concentrations of 71, 65 and 65 mg L⁻¹, respectively. In addition the transplants received 200 mg L⁻¹ K from KNO₃ and 46 mg L⁻¹ P from technical grade H₃PO₄ via the irrigation system. The seedlings in trays were grown on for one week and then transplanted to 3.7 cm diameter by 13 cm long plastic tubes with drainage holes and anti-spiral ribs (Super Stubby Cells Stewe and Sons, Corvallis, Ore.). The transplanted seedlings in the Stubby cells remained in the greenhouse until July, 1993 and then were placed outside on benches to harden off for two weeks before transplanting to the highway plot.

The field plot chosen for this study was a 20 m by 20 m plot located on a highway right-of-way median strip at the intersection of U.S. Highway 52 and Northwestern Blvd. just north of West Lafayette, IN. The soil type was originally a Crosby Silt Loam (fine, mixed, mesic Aeric Ochraqualf). The soil pH was 7.7 with a heavy clay texture, indicating that only a B-horizon subsoil remained after the original grading. Soil tests (Ohio Agricultural Research Station, personal comm.) revealed that soil available nitrogen was less than 6 kg ha⁻¹.

Available phosphorus at the site was 90 kg ha⁻¹. The dominant species on the site was *Festuca arundinacea* Schreb. which highway personnel have mowed an average of three times a year for approximately 20 years. The site was selected because of its lack of abrupt changes in topography and its 0-3 % slope from the highway to the center of the median area (Ulrich and Barnes, 1959).

We applied a 4% solution of glyphosate to one-half of the site on July 1. The remaining half of the site was mowed to an 8 cm height on July 11. We selected uniform plugs of *Ratibida pinnata* and *Andropogon gerardii* on July 13, 1993. Each *Ratibida pinnata* seedling was 17 mm in height and the height of each *Andropogon gerardii* seedling was 16 mm. 18 plugs of each species were placed in two rows 2 m apart on both the mowed area and the area pre-treated with glyphosate. Individual plants in each row were spaced 1.5 m apart. Transplanting of the seedlings took place in the morning hours two days after 4.8 cm of rain fell on the site. 1.8 cm of

rain fell on the site two days after the plugs were transplanted. The transplants received no maintenance or watering after installation.

In Sept., 1993, data were collected on plant height, and the number of shoots-per-plant for both species. In Oct., 1994, we recorded plant height, and survival for *Andropogon gerardii*. We recorded the the number of shoots-per- plant only for *Ratibida pinnata* seedlings in 1994. Plant height and survival data for both species were again measured in July, 1995. At that time, top growth of all the seedlings was excised at the soil line, oven dried at 80C for 48 hours, and weighed. Plant height and shoot-plus-leaf dry weight were analyzed using SuperAnova (Abacus Concepts, Berkeley, Calif.). A one-factor ANOVA with treatment as a main effect was used. Post-hoc tests of means were examined using Fisher's Protected Test.

5.3.3. Analysis of Data

5.3.3.1. Year One

All of the seedlings of both species installed in both treatment areas survived the first year. Plant heights of the grass species, but not the forb species, were significantly affected by site preparation in year one of this study. *Andropogon gerardii* seedlings transplanted in the area which was pre-treated with glyphosate averaged 37 cm taller than seedlings of *Andropogon* which were installed in the mowed area (Table 5.1). In contrast, plant heights of *Ratibida pinnata* seedlings planted in either the areas pre-treated with glyphosate or mowed were not significantly different.

The number of shoots-per-plant varied significantly between treatments for the grass species, but not the forb species in the first year of the study. *Andropogon gerardii* seedlings installed on the area pre-treated with glyphosate had five times as many shoots-per-plant compared with seedlings of *Andropogon* installed on the mowed area (Table 5.1). However, the number of shoots-per-plant of *Ratibida pinnata* seedlings did not vary significantly between treatments.

5.3.3.2. Year Two

All seedlings of both species in both treatment areas again survived into year two. Height data recorded in 1994 for both the grass and forb species were not consistent with the results of height data obtained in year one. For example, the height of *Andropogon gerardii* did not vary significantly ($p < .05$) between treatments in year two (Table 5.2). However, the height of *Ratibida pinnata* seedlings did vary significantly ($p = .002$) between treatments. Seedlings of *Ratibida pinnata* installed in the area pre-treated with glyphosate were more than 20 cm taller than seedlings of *Ratibida pinnata* installed on the mowed area (Table 5.2).

In contrast to year one, the number of shoots-per-plant of *Ratibida pinnata* varied significantly ($p < .001$) between treatments in year two. The number of shoots-per-plant of *Ratibida* seedlings installed on the area pre-treated with glyphosate remained the same as year one (Tables 5.1 & 5.2). However, the number of shoots-per-plant of *Ratibida pinnata* seedlings installed on the mowed area declined from year one to year two, so that the total average number of shoots-per-plant of *Ratibida* seedlings installed on the area pre-treated with glyphosate was 10 times the average number of shoots-per-plant of *Ratibida* seedlings installed on the mowed area (Table 5.2).

5.3.3.3. Year Three

All seedlings of both species survived into year three. *Andropogon gerardii* and *Ratibida pinnata* seedlings installed in the areas pre-treated with glyphosate were taller and shoot-plus-leaf dry weights were greater compared with seedlings installed in the mowed areas (Tables 5.1 & 5.3). In addition, *Ratibida pinnata* seedlings installed in the area pre-treated with glyphosate had over twice the number of shoots-per-plant than seedlings installed in the mowed area (Table 5.2).

5.3.4. Conclusions

5.3.4.1. Site Characteristics

Site pre-treatment with glyphosate resulted in areas infested with broad-leaved weedy species such as common lambsquarter (*Chenopodium album* L), rough fleabane (*Erigeron strigosus* Muhl.), and horseweed (*Conyza canadensis* (L.) Cronq.) which were present the second and third growing seasons. These species were not present on the site at the beginning of the experiment. Thus, dormant weed seed present at the soil surface may have germinated after the existing *Festuca* cover was eliminated, or may have been disseminated to the area by wind or birds. The mowed area did not exhibit broad-leaved weed invasion.

5.3.4.2. Growth

The growth of *Andropogon gerardii* and *Ratibida pinnata* seedlings was affected by site pre-treatment. At the end of each growing season, *Andropogon gerardii* seedlings were taller and had more shoots-per-plant when installed in an area pre-treated with glyphosate compared with seedlings installed in the mowed area. Three years after installation, the average dry weight of *Andropogon gerardii* seedlings installed in the area pre-treated with glyphosate was greater than seedlings installed on the mowed area. The existing *Festuca* sod on the mowed area may

have competed more effectively than the broad-leaved weeds on the area pre-treated with glyphosate with *Andropogon gerardii* seedlings for light, water and nutrients.

The growth of *Ratibida pinnata* seedlings was not significantly affected by site pre-treatment after the first growing season, but was significantly affected after years two and three. At least two reasons may explain the growth differences between years. The existing *Festuca* sod may have become dormant when the seedlings were planted the first year. Thus, competition between the existing *Festuca* and *Ratibida pinnata* seedlings may have been minimal. Secondly, the leaf area of the *Ratibida pinnata* seedlings was above the existing canopy of the *Festuca* sod at the time of transplanting. Thus, the developing *Ratibida pinnata* transplants were not shaded during first year growth.

5.3.4.3. Survival

All of the *Andropogon gerardii* and *Ratibida pinnata* seedlings installed on the highway right-of-way survived, regardless of site pre-treatment. Both *Ratibida pinnata* and *Andropogon gerardii* seedlings were able to survive regardless of competition from either *Festuca* sod (on the mowed area) or broad-leaved weed species which invaded the area pre-treated with glyphosate after the first growing season. Prairie species are deep-rooted (Weaver, 1954) which may allow them to survive competition from other species.

5.3.5. Recommendations

Seedlings of *Ratibida pinnata* and *Andropogon gerardii* can be successfully established on a highway right-of way. Both pre-treatment methods used in this study have advantages and disadvantages. Survival of either species over a three year period did not depend on site pre-treatment. However, pre-treatment with glyphosate before transplanting results in taller plants with more shoots compared with plants installed in the mowed area. However, broad-leaved weedy species invaded the areas where glyphosate was applied prior to transplanting. The resulting prairie seedling/weed area may not be considered by the public as aesthetically pleasing. Mowed areas remained free of broadleaved weed species, but resulted in poorer growth of the planted seedlings. Long-term growth and survival of the seedlings in a mowed area may also be questionable.

Transplanting seedlings of prairie forbs and grasses into "constructed" prairie areas consisting of easy-to-establish prairie grasses and forbs (Betz, 1986) on highway rights-of-way may be an alternative to the pre-treatment methods used in this study. These areas are easily established from seed and (with proper management) remain relatively free of weedy invaders. Warkins and Howell (1986) successfully transplanted forb seedlings into an established prairie

area. Transplanting prairie seedlings into constructed areas on highway rights-of-way may result in optimum growth, aesthetics, and survival.

5.4. Timing of Installation and Site Preparation Study

(Timing of Installation and Site Preparation Affect Survival, Plant Height, and Tillering of Wildflower Seedlings Installed on an Indiana Highway Right-of-way)

5.4.1. Literature Review and Specific Study Objectives

Quantitative research regarding site-preparation procedures and optimum times to establish prairie wildflower seedling transplants is limited. Nuzzo (1978) transplanted peat pots containing prairie species along Wisconsin highways. She reported that transplant success of the seedlings was species dependent. Nuzzo also reported that particular prairie seedlings were protected from harsh environmental conditions at those sites by existing weedy species. Christiansen (1967) reported that a greater percentage of prairie sod transplants survived when established on a bare field site compared with sod transplants installed on a site dominated by *Poa pratensis* L. Christiansen also reported that certain species of native prairie wildflowers survived at higher rates when transplanted either in early spring or fall. Curry (1980) showed that site preparation with mulch application or glyphosate application reduced weed populations compared with sites where either mulch or glyphosate were not applied. She also reported that survival of prairie wildflower seedlings on all sites was species dependent.

Researchers have not documented the effect of glyphosate application as a site pre-treatment on the survival and growth of prairie wildflowers installed on highway rights-of-way. Schramm (1978) documented the effect of the timing of installation on survival of prairie seedling transplants, but he only reported spring and late summer planting times. Finally, researchers have not fully investigated factors affecting the transplant success of prairie perennials grown in tree-seedling containers.

The objectives of this study were 1) to determine if timing of transplanting affects survival of prairie wildflower seedlings installed on a right-of-way, and 2) to determine if pre-plant site preparation (pre-treatment with glyphosate, mowing, or an existing prairie site with little diversity) affect survival and growth of prairie wildflower seedlings.

5.4.2. Work Plan

Seed of six species of prairie forbs, and one prairie grass species were purchased from Prairie Ridge Nursery, (Mt Horeb, Wis.) in Oct., 1993. The prairie forbs were: *Silene regia* Sims., *Aster novae-angliae* L., *Ratibida pinnata* (Venten.) Barnh., *Echinacea pallida* Nutt,

Liatris pycnostachya Michx., and *Veronicastrum virginicum*. (L.) Farw. *Andropogon gerardii* Vitm. was the grass species chosen for this study. The forb species were chosen because of their differences in rooting characteristics (Weaver, 1954) and transplant success (Schramm, 1972). *Andropogon gerardii* was chosen because it is one of the dominant grass species on a mesic prairie, and a comparison between forbs and a grass species was desired

We chose two sites for this study. The first site was a 30 m by 30 m plot in a wide median strip located 0.8 km northwest of West Lafayette, Tippecanoe Co., IN. near U.S. Highway 52 (52 site). The soil type of the 52 site was originally a Crosby Silt Loam (fine, mixed, mesic Aeric Ochraqualf). The soil pH was 7.7 with a heavy clay texture. A soil test revealed that the available nitrogen was less than 6 kg ha⁻¹. Available phosphorus was 90 kg ha⁻¹ (Ohio State Agricultural Testing Laboratory, personal comm.). The dominant species on the site was *Festuca arundinacea* Schreb. which had been mowed by highway personnel an average of three times a year for approximately 20 years.

The second site was a 30 m by 6 m plot located on 4 ha of right-of-way 4 km east of Lafayette, Tippecanoe Co., Indiana, near Indiana State Highway 26, adjacent to an entrance ramp leading to a freeway (26 site). The original soil type of the 26 site was a Glenhall Silt Loam (fine, mixed, mesic, Mollic Hapludaf) before highway construction (Ulrich and Barnes, 1959). In 1990, INDOT personnel used a Truax Drill to seed the site with a prairie wildflower mix. In 1994, *Andropogon gerardii* and *Schizachyrium scoparium* (Michx.) Nash. dominated the area. *Ratibida pinnata* was one of the few prairie forb species found at this site.

The soil pH at the site was 7.9. Available N was very low (< 6 kg ha⁻¹) with available phosphorus also low at 22 kg ha⁻¹ (Ohio State Agricultural Testing Laboratory, personal comm.). The area was mowed to a 20 cm height in October of each year.

The seed of all species was stored at 4C until the experiment began in Jan., 1994. We then filled seedling trays with a steam-pasteurized (80C) mix containing 2:2:1 (v/v/v) ratio of perlite, sphagnum peat moss and soil amended with 890 g Ca (H₂PO₄)₂, 593 g KNO₃, 593 g MgSO₄, 4.75 kg ground limestone and 74.2 Peters fritted trace elements No. 555, all per cubic meter of mix. We placed the forb and grass seed on top of the mix in the seedling trays, and placed the trays under intermittent mist for 10 days until the seeds germinated. The seedling trays containing the emerging seedlings were then transferred to a greenhouse bench where they were watered daily. The plants were fertilized at each watering with 201 mg L⁻¹ N: this was supplied from KNO₃, Ca (NO₃)₂, and NH₄NO₃ at concentrations of 71, 65 and 65 mg L⁻¹, respectively. In addition, the transplants received 200 mg L⁻¹ K from KNO₃ and 46 L⁻¹ P from technical grade H₃PO₄ via the irrigation system. After one week, the seedlings were transplanted to 3.7 cm diameter by 13 cm plastic growing tubes (Super Stubby cells, Stewe and Sons, Corvallis, Oregon). The seedlings remained on the greenhouse bench after transplanting for 3-4 weeks.

The transplants were then moved to a clear polyethylene-covered cold frame to harden off after visual inspection of the seedlings confirmed that the roots had filled the container. In May, 1994, the polyethylene film was removed from the cold frame. The seedlings were exposed to ambient conditions for the rest of the year. During the growing season, the top growth of the transplants was clipped at monthly intervals to maintain uniform heights of 10 cm for each species. Thus, individual transplants that were selected for later installation in the field plots had the same amount of top growth as transplants installed earlier in the season. Air pruning of the roots occurred in the Stubby containers, so that the available root volume of each transplant remained the same once the roots of each species filled each container.

One-half of the 52 site was sprayed with a 4% solution of glyphosate ten days before the seedlings were installed in Mar., 1994. We mowed the remaining one-half of the 52 site to a 15 cm height immediately before planting. The 26 site was used in its extant condition.

The seedlings were planted in a split-plot experimental design with site pre-treatment as main blocks and month of planting as subplots. We planted seven seedlings of each species at each treatment area at monthly intervals from Mar., 1994 until Nov., 1994 at the 52 and 26 sites. Planting date for each month differed, but all of the seedlings were installed between the tenth day and the twentieth day of each month. We installed the seedlings within 5 days after a measurable rain. Seedlings of each species were placed in separate rows 1 meter apart using a planting dibble (Stewe & Sons, Corvallis, Ore.), which matched the shape and size of the Super Stubby cells. Individual transplants in the rows were spaced 0.5 m apart. *Ratibida pinnata* and *Andropogon gerardii* seedlings were not installed at the 26 site because identification of these particular transplants would have been difficult since both species already existed on the site.

The Tippecanoe Co. area received average total precipitation during 1994, although above average rainfall was reported during the summer months. Below average precipitation was observed during the months of March, April, June, September, and October (J.R. McIntyre, National Weather Service, personal comm.).

Data on survival, plant height, and shoots-per-plant were collected on site in June, 1995. Shoot-plus-leaf dry weights were obtained by removing the top portion of each seedling above the soil line. Each portion was then placed in a paper bag and placed in a drying oven at 80 C for 48 hours. All data was then subjected to ANOVA using SuperAnova (Abacus Concepts, Berkeley, Calif.). Tests of means were subjected to Fisher's Protected Test.

5.4.3. Analysis of Data

Due to differences in variances between species, ANOVA statistics were analyzed for each individual species instead of a combined whole. Also, *Liatris pycnostachya* and *Echinacea*

pallida seedlings survived at very low rates which prevented ANOVA analysis for site pre-treatment effects.

5.4.3.1. Survival

Overall survival / Individual species. Overall survival rates varied greatly among species. Over 75% of *Ratibida pinnata*, *Andropogon gerardii*, and *Aster novae-angliae* seedlings survived the first year, while less than 15% of either *Liatris pycnostachya* or *Echinacea pallida* seedlings survived (Table 5.4).

Survival by month / Combined species. Combined monthly survival rates for all treatment areas and all species show that overall survival rates varied between planting months. Less than 45% of all seedlings survived when planted in March, April, or October, while more than 58% of the seedlings survived when planted in June, July, August, and September (Table 5.5).

Survival by month / Individual species. In general, seedlings of individual species showed the same trend in survival as combined rates of overall survival with lower survival rates in the early spring months and October (Table 5.6). However, *Veronicastrum virginicum* seedlings survived poorly when planted in July.

Survival related to site pre-treatment / Individual species. Overall survival rates of individual species varied between site pre-treatments. Seedlings of *Ratibida pinnata* planted on the area pre-treated with glyphosate survived at higher rates compared with seedlings installed on the mowed area (Table 5.6). However, seedlings of *Echinacea pallida*, *Liatris pycnostachya*, and *Veronicastrum virginicum* survived at higher rates when installed in the constructed prairie. Overall survival of *Aster novae-angliae* and *Andropogon gerardii* seedlings did not vary between treatments, but *Silene regia* seedlings survived at lower rates in the constructed prairie area.

5.4.3.2. Shoot-Plus-Leaf Dry Weight

Treatment effects. Shoot-plus-leaf dry weight varied between sites for individual species. Seedlings of *Ratibida pinnata* and *Aster novae-angliae* installed in the area pre-treated with glyphosate weighed over three times as much as seedlings installed in the mowed area (Table 5.7). Seedlings of *Silene regia* weighed significantly more ($p < 0.05$) than seedlings grown in the constructed prairie. Finally, seedlings of *Aster novae-angliae* installed on the area pre-treated with glyphosate weighed over 17 times more than seedlings installed on the constructed prairie.

Timing effects. In general, shoot-plus-leaf dry weights of individual species were highest when the seedlings were planted from June through September. Seedlings planted in March,

April, and October weighed less (Table 5.8). Dry weights of *Andropogon gerardii* were highest when the seedlings were planted from March through July.

5.4.3.3. Shoots-Per-Plant

Treatment effects. Significantly more ($p < 0.05$) shoots-per-plant were found on *Ratibida pinnata*, *Silene regia*, and *Aster novae angliae* seedlings installed on the area pre-treated with glyphosate compared with the other treatment areas (Table 5.9). However, seedlings of the remaining prairie species did not vary significantly between treatments.

Timing effects. More shoots-per-plant were found on seedlings of *Silene regia*, *Veronicastrum virginicum*, and *Aster novae-angliae* planted in August and September (Table 5.10). However, planting time did not significantly affect the number of shoots-per-plant of the other prairie species.

5.4.3.4. Plant Height

Treatment effects. Plant height of *Ratibida pinnata*, and *Aster novae-angliae* varied significantly ($p < 0.05$) between treatments. Seedlings of *Ratibida pinnata* and *Aster novae-angliae* installed on the area pre-treated with glyphosate were nearly twice as tall as seedlings planted in the other areas (Table 5.11).

Timing effects. *Andropogon gerardii* seedlings grew the tallest when planted in the spring months (Table 5.12). In contrast, seedlings of *Ratibida pinnata*, *Echinacea pallida*, *Liatris pycnostachya*, and *Veronicastrum virginicum* grew taller when planted from June through August. *Silene regia* seedlings were tallest when planted in October, compared with *Aster novae-angliae* seedlings which were taller when planted in April.

5.4.4. Conclusions

The results of this study must be examined with caution, since it was terminated after only one year. However, general trends in the data suggest that particular treatments and planting times may exist for individual species of prairie perennials.

5.4.4.1. Site Preparation and Survival

In general, the survival of seedlings of *Ratibida pinnata*, *Andropogon gerardii* and *Aster novae angliae* was not dependent on site pre-treatment. These results agree with the results obtained in a previous study where survival of *Ratibida pinnata* and *Andropogon gerardii* seedlings was not affected by site preparation (Kemery and Dana, unpublished data).

However, *Echinacea pallida*, *Liatris pycnostachya*, and *Veronicastrum virginicum* seedlings survived at much higher percentages when installed on the constructed prairie. These

species are considered more difficult to transplant successfully than *Ratibida*, *Andropogon*, or *Aster*, (Nuzzo, 1978; Christiansen, 1967, Schulenburg, 1972) and may have survived at higher rates in the constructed prairie because of less weed competition and protection from harsh environmental conditions compared with either the mowed area or the area pre-treated with glyphosate.

Conversely, *Silene regia* seedlings installed on the prairie area did not survive as well as seedlings installed in the other areas. However, many of the seedlings of *Silene regia* were suffering from extreme drought stress and may not have survived the growing season. Thus, the survival percentages for *Silene regia* seedlings may be higher than values that would have been obtained if the data were taken later in the growing season.

5.4.4.2. Site Preparation and Growth

Individual species differed in growth response when installed on different sites. In general, site pre-treatment with glyphosate resulted in taller, more vigorous seedlings of *Ratibida pinnata*, *Aster novae-angliae*, and *Silene regia*. In particular, *Aster novae-angliae* seedlings were less vigorous when installed in the mowed or constructed prairie areas.

5.4.4.3. Timing of Installation

In general, seedlings installed in March, April, and October survived at lower rates and grew poorly compared with seedlings installed during the summer or November. These results conflict with results from other studies which recommend early spring or fall planting (Christiansen, 1967). Water availability during these months was low. However, survival rates were high in months where water availability was also low. Thus, water availability alone cannot account for the differences in survival between months of installation.

October may be a transition period for planting of prairie species because root development may not occur in the limited period before dormancy in late fall. We noticed poor root growth of seedlings transplanted in October and November the previous year. In June, 1995, we were able to pull many seedlings transplanted in October and November of 1994 directly out the ground with root systems still intact, indicating that they had not expanded into the surrounding soil (Fig. 9).

Cool temperatures may have adversely affected growth and survival of the prairie seedlings installed in the spring of 1994. The effects of temperature on prairie seedling root growth should be investigated further.

5.4.5. Recommendations

The results of this study suggest that planting seedlings of prairie species in constructed prairie areas with little diversity is the preferred method of installation on highway rights-of-way. The survival of almost all of the prairie seedlings investigated in this study was either promoted or not adversely affected by installation in the constructed prairie area. Also, the constructed prairie area had few weeds present on the site.

Several of the prairie species investigated in this study did show positive growth responses when installed in areas pre-treated with glyphosate. However, applying glyphosate to highway sites usually results in long-term competition from weedy species. Perhaps these particular species should be planted in bare areas within or immediately surrounding the prairie construction to maximize growth.

Planting prairie seedlings during the late summer months during periods of adequate rainfall results in optimum growth and survival. Early spring planting and October planting may be detrimental to growth and survival of prairie species. Longer term studies may be necessary to determine if the results we obtained only reflect optimum site preparation techniques and timing methods for any particular year.

5.5. Container Size and Water-Holding Polymers

(Container Size, Gel Type, and Species Affect Survival of Prairie Perennials on a Steep Bank on an Indiana Highway Right-of-way)

5.5.1. Literature Review and Specific Study Objective

Rights-of-way located near highway construction sites must be quickly re-planted to prevent site erosion or damage to the newly constructed roadway (Trautman and Lohmeyer, 1980). In particular, the re-establishment of vegetation on steep banks along many highway rights-of-way after construction is especially difficult because erosion on the sites is severe, the soil texture on the sites is very poor, nutrient availability is usually very low, and water availability to existing vegetation on such sites is very low (Hargett, et al., 1982). Steep banks also are difficult to maintain even if vegetation is established, because mowing bank vegetation is often difficult or impossible.

Highway vegetation planners have used hydroseeding, seeding with herbaceous perennial groundcover species other than grasses, seedling-mat installation, hardwood mulch installation, and installation of limestone rock in an attempt to control erosion and prevent weed invasion on steep banks on highway rights-of-way. However, all such methods may be ineffective in erosion or weed control, are not considered aesthetically pleasing, or are cost prohibitive (Hargett, et al, 1982; Osborne and Gilbert, 1978).

The establishment of prairie perennial transplants on steep banks located on highway rights-of-way may be a cost-effective technique to control erosion, provide aesthetics, and control weeds. Native prairie plants are deep rooted, and can survive extended periods of drought (Weaver, 1954). Established prairie communities resist weed invasion if not disturbed, and the installation of prairie species near highways is considered to be a cost-effective and aesthetically pleasing alternative to turf monocultures (Harrington, 1994).

The success of seedling transplants on steep banks on highway rights-of way is dependent on many factors including species, transplant container size, and the soil mixture in the container. Nuzzo (1978) was successful in her effort to plant seedlings of prairie perennials along Wisconsin roadsides in drought conditions. While Nuzzo did not transplant prairie species on steep banks, she did determine that survival of prairie seedlings on droughty sites (similar to conditions found on highway backslopes) was species dependent (Nuzzo, 1978).

Researchers have thoroughly documented the effect of container size on horticultural crop species. Plants grown in small containers often show limited growth due to low water availability (Milks, et al., 1989). Growth and survival of bell pepper and marigold seedlings grown in small containers often is poor compared with seedlings grown in larger containers and transplanted to the field (Latimer, J.B., 1991; Neesmith, et al, 1992). One-liter plastic bags and 4 cm peat containers have been used on a limited scale to grow transplants of prairie perennials for a field study in Iowa, but the effect of transplant container size was not reported (Christiansen, 1967). The use of containers that allow more depth for root growth of deeply rooted prairie species and also provide more water holding capacity may allow prairie species to survive on steep banks located on highway rights-of-way.

Researchers have recently studied the impact of hydrophilic or starch-based polymer gels (hydrogels) in increasing the water-holding capacity of container mixes for vegetables and bedding plants (Gehring and Lewis, 1980; Wang, 1989). Hydrogels incorporated into soilless greenhouse mixes used in container production are particularly effective when the seedlings are transplanted to situations where both soil fertility and water availability are low (Henderson and Hensley, 1990; Sayed, et al., 1991). Since many highway rights-of-way sites are characterized by low fertility and droughty conditions, hydrogels used as container-media additives may increase the survival of prairie species transplanted on steep banks on highway rights-of-way by increasing the water-holding capacity of the medium immediately surrounding the roots of the newly installed seedlings.

Researchers have not investigated the effect of container size or the addition of hydrogels to the soil of container-grown seedlings of native prairie perennials. Prairie species have been transplanted to harsh conditions on a borrow pit in Ohio (Conover and Geiger, 1989), but

researchers have not investigated the survival of seedlings of prairie perennials on steep banks located on highway rights-of-way.

The objectives of this study were threefold. The first was to determine if transplants of native species installed on a steep highway-right-of-way bank could survive. Second was to observe if container size affected the survival and growth of particular species on a steep bank. The third objective was to determine if the incorporation of water-holding hydrogels in the container medium of transplants of prairie perennials installed on a steep bank would affect survival and growth of the transplanted seedlings.

5.5.2. Work Plan

Three species of prairie wildflowers and one native grass were selected for this study. The prairie forb species were: *Ratibida pinnata* (Venten.) Barnh., *Echinacea pallida* Nutt., and *Liatris aspera* Michx. *Schizachyrium scoparium* (Michx.) Nash. was the prairie grass species chosen for this study. The forb species were selected to gain a representative sample of prairie species with different transplant survival characteristics (Schulenberg, 1972). The prairie grass was chosen because it is tolerant of drought and a comparison between a grass and forb species was desired.

We obtained seed of the prairie forb species in Oct., 1993, from Prairie Ridge Nursery (Mt. Horeb, Wis.). *Schizachyrium scoparium* seed was obtained in Oct., 1993 from Sharp Brothers Inc. (Clinton, Mo.). The forb and grass seed was stored at 4C until the experiment began in Jan., 1994. We filled seedling trays with a steam-pasteurized (80C) mix containing 2:2:1 (v/v/v) ratio of perlite, sphagnum peat moss and soil amended with 890 g Ca (H₂PO₄)₂, 593 g KNO₃, 593 g MgSO₄, 4.75 kg ground limestone and 74.2 Peters fritted trace elements No. 555, all per cubic meter of mix. We placed the forb and grass seed on top of the medium in the seedling trays, and placed the trays under intermittent mist for 10 days until the seeds germinated. The seedling trays containing the emerging seedlings were then transferred to a greenhouse bench where they were watered daily. The plants were fertilized at each watering with 201 mg L⁻¹ N: this was supplied from KNO₃, Ca (NO₃)₂, and NH₄NO₃ at concentrations of 71, 65 and 65 mg L⁻¹, respectively. In addition the transplants received 200 mg L⁻¹ K from KNO₃ and 46 mg L⁻¹ P from technical grade H₃PO₄ via the irrigation system. After two weeks, 15 uniform seedlings of each species were transferred to each of the following container systems / treatments:

Treatment 1. Super Stubby cells (Stewe and Sons, Inc, Corvallis, Ore.) 3.7 cm diameter by 13 cm growing tubes filled with the container growing medium described previously.

Treatment 2. Super cells (Stewe and Sons, Inc.) 3.7 cm diameter by 18 cm growing tubes filled with the same medium as Treatment 1.

Treatment 3. Super Stubby cells filled with the container growing medium to which 2240 g m³ of Terrasorb GB (Industrial Services International, Bradenton, Fla.) was added.

Treatment 4. Super cells filled with the same medium as Treatment 3.

Treatment 5. Super Stubby cells filled with the container growing medium to which 2240 g m³ of Liqua-Gel (Miller Chemical and Fertilizer, Hanover Pa.) was added.

Treatment 6. Super cells filled with the same medium as Treatment 5.

Treatment 7. Super Stubby cells filled with the container growing medium to which 20 ml of a 4% solution of compound GLK-8924 was added 24 hrs before transplanting to the field. GLK-8924 is an experimental chemical developed by Great Lakes Chemical Corp. (West Lafayette, Ind.) which has shown promise as a soil additive in current drought studies of tomato (Joly, 1995 personal comm.)

Treatment 8. Super cells filled with the same medium and solution as Treatment 7.

A 3/4 rate of gel polymer to greenhouse mix (Treatments 4-6) was used because full rates resulted in heavy mixtures that stuck to the sides of the Stubby cells. The stickiness of the mixture made it impossible to extract the transplants from the containers without damaging the root systems of the transplants. Only *Echinacea pallida* and *Ratibida pinnata* seedlings received treatment 7 and 8. The seedlings remained on the greenhouse bench after transplanting for 3-4 weeks. They were then moved to a clear polyethylene-film- covered cold frame to harden off after visual inspection of the seedlings confirmed that the roots had filled the container. In May, 1994 the polyethylene film was removed from the cold frame. The seedlings were exposed to ambient conditions until they were transplanted to the field plot.

The field plot was located 8 km north of Lafayette, Indiana on a steep bank in the infield of an Interstate highway interchange. The original soil was classified a Hennepin Loam (fine loamy, mixed mesic Typic Entrochrept) with a 20-50% slope (Ulrich and Barnes, 1959) before the highway was constructed. The existing soil at the time of the study had a pH of 7.5 with a heavy clay texture, suggesting that only a B-horizon subsoil was present.

The seedlings were transplanted to the slope on May 10, 1994 in a completely randomized design using a planting dibble (Stewe and Sons, Inc, Corvallis, Ore.). The soil at the site was still moist due to rain the previous week. Two days after we installed the transplants, 4.5 cm of rain fell on the site. In Aug., 1994, survival data, plant height, and the number of vegetative shoots-per-plant were recorded. In June, 1995, survival data, plant height and flower shoots per-plant were recorded. Data on individual species was recorded after each species began to flower. The above-ground portions of each plant were excised at the soil line and placed into individual paper bags. The bags containing the leaf and shoot tissue were dried for 48 hours at

80 C. The plant material was removed from each bag and weighed to determine leaf-plus-shoot dry weight. Flower shoots were recorded only in 1995 because the plants did not flower in 1994. All data was then subjected to ANOVA using SuperAnova (Abacus Concepts, Berkeley, Calif.). Tests of means were subjected to Fisher's Protected Test.

The site received average total precipitation during 1994, although above average rainfall was reported during the summer months. Below average rainfall was observed during the months of Mar., April, June, Sept., and Oct. (J.R. McIntyre, National Weather Service, personal comm.).

5.5.3. Analysis of Data

5.5.3.1. Year One-1994

Survival. 87% of the seedlings survived 3 months after installation on the steep bank. All *Ratibida pinnata* seedlings survived, but less than 63% of the *Liatris aspera* seedlings survived the first three months after transplanting. Less than 80% of *Schizachyrium scoparium* seedlings survived three months after transplanting (Table 5.13).

Seedling survival was affected by container depth and hydrogel amendment to the container. *Schizachyrium scoparium* seedlings amended with hydrogels survived at higher rates compared with seedlings grown in greenhouse mix only (Table 5.14). *Liatris aspera* seedlings grown in larger containers survived at higher rates than *Liatris* grown in smaller containers (Table 5.15).

Shoots-per-Plant. We observed no significant differences in the number of shoots-per-plant between seedlings amended with hydrogels or controls in year one of this study.

Plant Height. Plant height was not affected by hydrogel amendment, except for seedlings of *Schizachyrium scoparium*. These seedlings amended with hydrogels were significantly shorter ($p < .01$) than seedlings grown only in greenhouse mix (Table 5.16).

5.5.3.2. Year Two-1995

Survival. 75% of the seedlings survived through June, 1995. Sharp reductions in survival percentages were observed for *Liatris aspera* and *Echinacea pallida* (Table 5.13). Similar to year one, *Schizachyrium scoparium* seedlings grown in media amended with hydrogels survived at higher rates compared with control plants (Table 5.14). However, *Liatris aspera* seedlings in the hydrogel treatments survived at lower rates compared with seedlings grown only in greenhouse mix.

There was little effect of container depth on survival of prairie seedlings, except for *Liatris aspera*. Almost twice as many seedlings survived when transplanted in 18 cm containers compared with seedlings transplanted in 13 cm containers (Table 5.15).

Flower shoots-per-plant. There was little effect of either container depth or hydrogel amendment on flower shoots of the prairie seedlings, except for *Ratibida pinnata*. Seedlings of *Ratibida pinnata* had significantly fewer ($p < 0.05$) flower shoots-per-plant when GLK-8924 was used as an amendment compared with the other hydrogels and control plants (Table 5.17). However, *Ratibida pinnata* seedlings grown in 18 cm containers had significantly more ($p < 0.05$) flower shoots-per-plant compared with seedlings grown in 13 cm containers (Table 5.18).

Plant height. Plant height of both *Ratibida pinnata* and *Echinacea pallida* seedlings was affected by amendment with GLK-8924. Both species were significantly shorter ($p < 0.05$) when GLK-8924 was used as a soil amendment compared with all other treatments. We observed no significant differences in plant height based on container size.

Shoot-plus-leaf dry weight. We observed no significant effects of hydrogel amendments upon shoot-plus-leaf dry weight in year two of the study. In contrast, container size did affect shoot-plus-leaf dry weight of two prairie species. Seedlings of *Ratibida pinnata* and *Echinacea pallida* grown in 18 cm containers weighed significantly more ($p < 0.05$) than seedlings grown in 13 cm containers (Table 5.19).

5.5.4. Conclusions

The survival rate of *Echinacea pallida* on a steep bank was especially surprising, since survival rates of this species in our other studies have been low (Kemery and Dana, unpublished data). Perhaps *Echinacea pallida* would survive at higher percentages on sites that are very well drained. The low survival percentage of *Liatris aspera* was not surprising, considering that it is a prairie species that occurs on mesic sites (Curtis and Greene, 1949).

We observed little effect of hydrogel amendment upon survival and growth of the prairie species, except for GLK-8924. This experimental compound caused a reduction of seedling growth. Further work with different rates and different species of prairie forbs on even harsher sites may provide more information about the possible value of this compound.

In general, prairie seedlings grown in deeper containers were slightly more vigorous than plants grown in shallow containers. However, no differences in overall survival were evident, except for *Liatris aspera*. This species may need a large container for its corm and long tap root (Weaver, 1954) to survive at greater percentages on harsh sites.

Perhaps the most interesting observation obtained in this study was the ability of prairie forbs to withstand severe erosion. Research to determine the erosion control capacity of prairie

seedlings may offer alternatives to current erosion-control methods for state transportation personnel.

5.5.5. Recommendations

Seedlings of prairie perennials can be successfully established on steep banks along highways characterized by low fertility and low water availability. The survival of prairie perennial seedlings installed on a steep bank on a highway right-of-way is not affected by hydrogel amendment to the container media. The experimental compound GLK-8924 may reduce or delay growth of prairie perennials.

Prairie perennials grown in larger containers were slightly more vigorous than seedlings grown in smaller containers. Larger containers may be necessary to optimize survival rates of prairie perennial species that are difficult to transplant. However, the use of hydrogels as soil amendments or the use of deeper containers to enhance survival of prairie perennial seedlings installed on steep right-of-way banks is not recommended.

5.6. Vesicular-Arbuscular Mycorrhizae

(Seedling Inoculation with Vesicular-Arbuscular Mycorrhizae Affects Growth of Prairie Perennials Installed on an Indiana Highway Right-of-way)

5.6.1. Literature Review and Specific Study Objectives

Vesicular-arbuscular mycorrhizal (VAM) fungi are obligate parasites which form symbiotic relationships with plant roots, especially in low phosphorus soils (Bentivenga and Hetrick, 1992). VAM have been associated with increased phosphorus uptake, increased growth, and increased drought resistance due to an extended nutrient uptake zone of roots of many species (Hayman, 1982). Most grasses and forbs of the tall-grass prairie associate with VAM fungi and benefit from VAM inoculation (Anderson, et al., 1984; Miller, 1986). For example, seedlings of *Baptisia australis* L., *Liatris aspera* Michx., and *Asclepias tuberosa* L. inoculated with four species of VA mycorrhizae were taller and flowered more compared with non-inoculated control plants after two growing seasons (Zajicek, et al, 1987). Mycorrhizal inoculation of *Castilleja coccinea* (L.) K. Spreng. and *Oenothera speciosa* Nutt. seedlings placed in a field setting resulted in taller plants with more branches than non-inoculated plants (Crank, 1991).

Seedlings with mycorrhiza out-perform non-mycorrhizal seedlings in situations where moisture, stress, low fertility, and pH extremes occur (Maroneck, et al., 1981). VAM inoculated seedlings have been installed on disturbed soils and eroded lands such as coal spoils to improve

survival percentages of the seedlings compared with non-inoculated seedlings, and also to re-introduce VAM to disturbed areas where VAM soil populations are lacking (St. John and Evans, 1994; Harris and Jurgenson, 1977; Marx and Artman, 1979).

Sites located on highway rights-of-way in the Midwest often are characterized by low fertility, soil compaction, and high pH (Harrington, 1994). Hence, prairie seedlings inoculated with VAM may survive better on highway rights-of-way compared with non-inoculated seedlings of prairie plants.

Different species of VAM have different growth promotional effects on particular species (Daniels and Menge, 1981). For example, McArthur and Knowles (1993) reported a greater growth response of potato seedlings inoculated with *Glomus interadici* Schenk and Smith compared with potato plants inoculated with *Glomus mosseae* (Nicol. and Gerdemann) Gerdemann and Trappe. Inoculation with *Glomus etunicatum* Becker and Gerdman resulted in a greater shoot mass of *Macroptilium atropurpureum* Urb. than seedlings inoculated with *Glomus interadici* in a non-pasteurized field soil (Medina, et.al, 1990). Thus, particular species of VAM may produce different growth responses in seedlings planted on particular sites located on highway rights-of-way.

The first objective of this study was to determine if inoculation of prairie perennial seedlings with VAM would result in greater survival rates and increased growth compared with non-inoculated prairie perennial seedlings transplanted on a highway right-of-way. The second objective was to determine if different species of VAM produce different growth responses and survival percentages in particular species of prairie perennial seedlings installed on a highway right-of-way.

5.6.2. Work Plan

Seed of four species of prairie forbs was obtained in Oct., 1992, from Prairie Ridge Nursery (Mt. Horeb, Wis.). The species of prairie wildflowers were: *Phlox pilosa* L., *Echinacea pallida* Nutt., *Liatris pycnostachya* Michx., and *Ratibida pinnata* (Venten) Barnh. The four species were chosen in order to gain a representative sample of prairie forbs with different rooting characteristics (Weaver, 1954) and transplant success (Schramm, 1972). The seed was stored at 4C until the experiment began in Jan., 1994.

Two VAM cultures were obtained from the International Culture Collection of Vesicular-Arbuscular Mycorrhizae, West Virginia University (INVAM) in July, 1994. The two species of fungi obtained from INVAM and present in separate cultures were *Glomus interadici* and *Gigaspora margarita* Becker and Hall. Both *Glomus* and *Gigaspora* were recommended by INVAM because each genus was well represented in prairie regions of the U.S. (Bentivenga, personal comm.) The two species of fungi were each maintained in sand cultures (3:1 sand /

greenhouse mix) using Sudan grass (*Sorghum sudanense* (Piper) Stapf. 'Sudex') as a non-specific host. The greenhouse medium used in the sand cultures was a steam-pasteurized (80C) mix containing 2:2:1 (v/v/v) ratio of perlite, sphagnum peat moss and soil amended with 890 g Ca (H₂PO₄)₂, 593 g KNO₃, 593 g MgSO₄, 4.75 kg ground limestone and 74.2 Peters fritted trace elements No. 555, all per cubic meter of mix.

Soil was collected from Ambia-Talbot prairie remnant in Oct., 1993, and maintained in a sand culture with Sudan grass as described previously. Ambia-Talbot is an undisturbed prairie remnant located 45 k northwest of Lafayette, Indiana near the Indiana / Illinois state line. The soil at the site was classified as a Chalmers Silt loam (fine silty, mixed, mesic Typic Haplaquoll) (Ulrich and Barnes, 1959). The soil pH was 6.8, with less than 6 kg ha⁻¹ N. The soil available P was 78 kg ha⁻¹. Samples of the Ambia-Talbot soil were sent to INVAM for species identification of any VA mycorrhizae that were present in the soil.

The Ambia-Talbot soil contained *Glomus mossea*, *Glomus geosporum* (Nicol and Gerd) Gerdemann and Trappe., and another undescribed *Glomus* species (Bentivenga, personal comm.). The Ambia-Talbot soil was used as an inoculum because of its growth-promotion of Sudan grass compared to other soil inoculum obtained from other remnant sites (Kemery and Dana, 1995).

We examined Sudan grass roots from each of the sand cultures described previously to confirm VAM inoculation of the roots. Sudan grass root sections were randomly collected from each container, cleared, and stained using a containerized system of Claassen and Zasoski (1992) with the staining procedures of Koske and Gemma (1989). VAM inoculation was confirmed on all of the cultures used in this study. We observed many spores and hyphal segments on the root samples.

The Sudan grass was clipped to the soil line on each of the culture containers. The root mass from each container was cut into 3 cm segments using sterilized garden shears, and mixed thoroughly with the remaining sand/soil mix left in the container. This mixture was then combined at a 1:3 vol/vol ratio with the pasteurized greenhouse growing medium described previously. A 1:3 vol/vol mix was used because previous studies by the author have shown that this ratio results in rapid and complete inoculation of the container system used in this experiment. Care was taken to avoid contamination of the mixes. Each mix of VAM and greenhouse soil was prepared separately, and shears were sterilized with sodium hypo-chlorite before each use.

In Jan., 1994, we placed the forb and grass seed on top of peat-lite in seedling trays, and placed the trays under intermittent mist for 10 days until the seeds germinated. The trays containing the emerging seedlings were transferred to a greenhouse bench where they were watered daily. The plants were fertilized at each watering with 201 mg L⁻¹ N: this was supplied

from KNO_3 , $\text{Ca}(\text{NO}_3)_2$, and NH_4NO_3 at concentrations of 71, 65 and 65 mg L^{-1} , respectively. In addition the transplants received 200 mg L^{-1} K from KNO_3 and 46 mg L^{-1} P from technical grade H_3PO_4 via the irrigation system.

After two weeks of growth in the greenhouse, uniform seedlings of each species were transplanted to 3.7 cm by 11.5 cm plastic Super Stubby cells (Stewe and Sons, Corvallis, Ore.) in which 15 seedlings of each species were assigned to each of the following treatments:

Treatment 1. Stubby cells filled with a 1:3 (vol/vol) sand to pasteurized greenhouse medium.

Treatment 2. Stubby cells filled with a 1:3 vol/vol mixture of *Glomus interadicies* inoculum and greenhouse medium.

Treatment 3. Stubby cells filled with a 1:3 vol/vol mixture of *Gigaspora margarita* inoculum and greenhouse medium.

Treatment 4. Stubby cells filled with a 1:3 vol/vol mixture of Ambia-Talbot inoculum and greenhouse medium.

Treatment 5. Stubby cells filled with a 1:3 vol/vol mixture of inoculum cocktail (equal portions of all cultures to make a 25% portion) and greenhouse mix.

Echinacea pallida seedlings were not inoculated with Ambia-Talbot soil due to a shortage of material. All transplanted species remained in the greenhouse until May, 1994. The transplants were then moved to a cold frame and exposed to ambient conditions for 2 weeks until field transplanting.

The site chosen for this study was a 100 m by 20 m plot located on a 2 ha highway right-of-way located 6 k east of Lafayette, Indiana. The soil at the site was classified as a Glenhall silt loam with a 0/2% slope (A fine-loamy, mixed mesic, mollic Hapludaf) before highway construction in 1960 (Ulrich and Barnes, 1959). The soil pH of the site at the time of the study was 7.9. The extant soil texture was a heavy clay, eroded at many spots, with the surface of the site littered with small chunks of asphalt and concrete, suggesting that none of the site's original topsoil remained after highway construction. *Festuca arundinacea* Schreb. was the dominant species at the site. This grass species was located in patches on the highly compacted mineral soil. Soil tests (Ohio Agricultural Research Center, personal comm.) revealed that less than 6 kg ha^{-1} N, and 115 kg ha^{-1} P were present. We chose the site for this particular study because of its poor soil texture which is typical of many highway right-of-way sites.

We sprayed the site with a 4% solution of glyphosate (Round-up) herbicide two weeks prior to transplanting the prairie forbs to kill the existing *Festuca arundinacea* turf. We transplanted the Stubby cells containing the prairie forb seedlings on May 10, 1994, in a completely randomized design. Each individual transplant was spaced 45 cm apart, in rows that were spaced 60 cm apart. We installed each transplant using a large planting dibble (Stewe and

Sons, Corvallis, Ore.) that matched the size of the Stubby containers. The soil at the site was moist, resulting from 1.8 cm of rain 5 days before planting. Two days after the site was planted, 4.5 cm of rain fell on the site. The seedlings were not watered at or after installation. Precipitation amounts in 1994 were normal, but above average amounts of rainfall were recorded from May through July (J.R. McIntyre, National Weather Service, personal comm.). We did not use any weed control measures after the seedlings were transplanted to the site.

5.6.2.1. Data Collection 1994

In Aug., 1994, we recorded survival, plant height and vegetative shoot number of *Ratibida pinnata* and *Echinacea pallida* seedlings, because they were the only species which produced measurable top growth in 1994. The site was very weedy, dominated by common ragweed (*Ambrosia artemisiifolia* L), giant foxtail (*Setaria faberi* Herrm.), and horseweed (*Conyza canadensis* (L.) Cronq.

5.6.2.2. Data Collection 1995

Data was collected after each species reached anthesis. We recorded survival, plant height, shoot number, and shoot-plus-leaf dry weight for *Phlox pilosa* in May, 1995, *Echinacea pallida* and *Liatris pycnostachya* in June, 1995, and *Ratibida pinnata* in July, 1995.

After each data collection, the above ground portions of the plant measured from soil line of each surviving transplant were removed and placed in individual paper bags. The paper bags containing the plant material were then placed in a drying oven for 48 hours at 80C. *Ratibida pinnata* seedlings were very large at the time of harvesting. Individual plants were placed in lawn waste bags and moved to a large drying room at 80C for 6 days. Shoot-plus-leaf dry weight of all transplants was determined.

The roots of three plants representing each species and treatment were randomly selected and dug from the site. 30 g samples randomly collected from each plant were combined in individual 25 ml containers. The combined root samples from each species and treatment were then stained using the methods of Koske and Gemma (1989). We determined the mean infection percentage of the stained root samples using the grid-line intersect method (Giovannetti and Mosse, 1980).

Analysis of variance (ANOVA) was conducted using SuperAnova (Abacus Concepts, Berkeley, Calif.). Post-hoc tests of means were conducted using Fisher's Protected Test.

5.6.3. Analysis of Data

5.6.3.1. Year One Results

Survival. 92% of the seedlings survived until Aug., 1994. There were no significant differences in survival between species or between treatments.

Shoots-per-plant. In contrast to survival, the number of shoots-per-plant did vary significantly between treatments for *Ratibida pinnata* seedlings, but not for *Echinacea pallida* seedlings. For example, VAM inoculated *Ratibida pinnata* seedlings had at least 4 more shoots-per-plant than non-inoculated *Ratibida* seedlings (Table 5.20). Seedlings inoculated with *Gigaspora margarita* (Treatment 3) and a 25% VAM cocktail (Treatment 5) had over 7 more shoots-per-plant than the non-inoculated control (Table 5.20).

The number of shoots-per-plant for *Echinacea pallida* seedlings did not vary significantly between treatments.

Plant Height. Plant height did not vary significantly between treatments for either species. However, non-inoculated seedlings of *Echinacea pallida* were slightly taller than seedlings inoculated with VAM (Table 21).

5.6.3.2. Year Two Results

Survival. All *Phlox pilosa* and *Ratibida pinnata* seedlings overwintered successfully. Less than 30% of *Liatris pycnostachya* seedlings survived (Table 5.22).

Height / Dry Weight / Shoots. No significant differences in either plant height, plant shoot-plus-leaf dry weight, or shoots-per-plant were observed in year two of this study, except for *Ratibida pinnata* (Table 5.23, 5.24, & 5.25). Seedlings of *Ratibida pinnata* inoculated with *Gigaspora margarita* had significantly more shoots-per-plant than the non-inoculated seedlings (Table 25).

Mean Infection Percentages. All of the seedlings were infected with VAM at the conclusion of the experiment. *Ratibida pinnata* seedlings exhibited the highest overall infection percentages, but all infection levels were low (Table 5.26). Only sparse hyphae were present on most seedling roots. Seedlings that were not inoculated at the start of the experiment were infected with VAM at the conclusion of the experiment, often at higher levels than seedlings inoculated with VAM at the beginning of the study (Table 5.26).

5.6.4. Conclusions

5.6.4.1. Year One

It was possible to measure growth only on two of the four prairie species at the end of the first growing season because the top growth of both *Phlox* and *Liatris* seedlings died back to the ground during the hot summer months. *Ratibida pinnata* was the only species in our study which showed a positive growth response to VAM inoculation.

Ratibida pinnata may have benefited more from an early VAM association because it was quicker to establish than the other prairie species. *Echinacea pallida* seedlings did not exhibit the same growth response to VAM inoculation as *Ratibida pinnata*. *Echinacea pallida* seedlings were still very small in Aug., 1994 (compared to *Ratibida pinnata*), and growth differences between individual plants may have been difficult to detect.

5.6.4.2. Year Two

Ratibida pinnata was again the only species which responded to VAM inoculation. Seedlings inoculated with *Gigaspora margarita* had more shoots-per-plants than the non-inoculated seedlings. Shoot-plus-leaf dry weight of *Ratibida pinnata* seedlings inoculated with *Gigaspora margarita* was higher than any other treatment. These results are surprising, considering that non-inoculated seedlings were inoculated with VAM at a higher percentage than *Gigaspora*. Perhaps the non-inoculated seedlings became infected with an indigenous VAM which did not elicit a significant growth response.

We were surprised by *Phlox pilosa* survival in this study. This species should be installed on other highway sites to determine if this showy spring species has potential for widespread installation on rights-of-way.

Mean infection percentages of all species and treatments were low. The high amount of available phosphorus at the site may have reduced the need for VAM inoculation of the prairie seedling roots. We do not know if the species of VAM present on the seedling roots at installation were still present on the samples at harvest. Perhaps an indigenous VAM species present at the site has replaced the VAM that were present on the seedlings at the beginning of the experiment.

Table 5.1. Height (cm) of *Andropogon gerardii* and *Ratibida pinnata* seedlings installed on a *Festuca arundinacea* site pre-treated with glyphosate or mowed. Values are means of 18 replicates.

Pre-Treatment	Height (cm)					
	Ratibida pinnata			Andropogon gerardii		
	Year 1	Year 2	Year 3	Year1	Year 2	Year 3
Glyphosate	20.3a ²	106.5a	64.3a	105.3a	169.0a	55.3a
Mowed	16.1a	85.5b	36.4b	68.2b	145.4a	41.0b
LSD 0.05	11.2	13.7	14.2	9.4	11.4	9.7

²Mean separation (In columns) by Fisher's protected test.

Table 5.2. Shoots-per-plant of *Andropogon gerardii* and *Ratibida pinnata* seedlings installed on a *Festuca arundinacea* site pre-treated with glyphosate or mowed. Values are means of 18 replicates.

Pre-Treatment	Shoots-Per-Plant					
	Ratibida pinnata			Andropogon gerardii		
	Year 1	Year 2	Year 3	Year1	Year 2	Year 3
Glyphosate	9.8a ²	10.7a	4.5a	5.3a	---	---
Mowed	8.7a	1.0b	2.1b	1.5b	---	---
LSD 0.05	2.7	3.1	2.0	3.1		

²Mean separation (In columns) by Fisher's protected test.

Table 5.3. 1995 Shoot-plus-leaf dry weight (g) of *Andropogon gerardii* and *Ratibida pinnata* seedlings installed on a *Festuca arundinacea* site pre-treated with glyphosate or mowed . Values are means of 18 replicates.

Pre-Treatment	Shoot-plus-leaf dry weight (g)	
	<i>Ratibida pinnata</i>	<i>Andropogon gerardii</i>
Glyphosate	18.8a ²	31.8a
Mowed	6.6a ²	12.5b
LSD 0.05	7.2	7.1

²Mean separation (In columns) by Fisher's protected test.

Table 5.4. Survival of prairie perennial seedlings installed on a *Festuca arundinacea* site pre-treated with glyphosate, mowed, or a constructed prairie.

Treatment	Survival %						
	<i>Ratibida pinnata</i>	<i>Andropogon gerardii</i>	<i>Echinacea pallida</i>	<i>Silene regia</i>	<i>Liatris pycnostachya</i>	<i>Veronicastrum virginicum</i>	<i>Aster novae-angliae</i>
Glyphosate	89	81	2	76	2	46	76
Mowed	73	79	3	79	2	38	74
Prairie	—	—	32	30	33	93	76
Mean	81	80	12	62	12	59	76

Table 5.5. Overall survival by month of prairie perennial seedlings installed along Indiana highway rights-of-way.

Month	Survival %
March	42
April	44
May	48
June	65
July	58
August	62
September	61
October	32
November	54

Table 5.6. Monthly survival of prairie perennial seedlings installed along Indiana highway rights-of-way.

Survival %							
Month	Ratibida	Andropogon	Echinacea	Silene	Liatris	Veronicastrum	Aster novae-
	pinnata	gerardii	pallida	regia	pycnostachya	virginicum	angliae
March	57	79	5	14	0	67	90
April	57	86	5	71	0	57	52
May	100	79	0	57	5	57	67
June	93	100	19	100	14	57	90
July	100	100	14	57	29	38	95
August	93	86	10	81	29	62	95
September	86	86	29	71	19	67	86
October	64	22	10	29	5	57	48
November	79	86	19	76	10	71	57

Table 5.7. Shoot-plus-leaf dry weight (g) of prairie perennial seedlings installed on a constructed prairie, on a *Festuca arundinacea* site pre-treated with glyphosate or mowed. Values are means of 63 replicates.

Treatment	Shoot-Plus-Leaf Dry Weight (g)						
	Ratibida pinnata	Andropogon gerardii	Echinacea pallida	Silene regia	Liatris pycnostachya	Veronicastrum virginicum	Aster novae- angliae
Glyphosate	11.3a ^z	4.6a	.2*	2.6a	2.8*	2.1a	17.6a
Mowed	3.6b	3.5a	1.1	2.0ab	.4	2.8a	5.2b
Prairie	—	—	4.9	1.1b	2.5	2.3a	1.8c
PSLD _{0.05}	5.3	.8	—	.5	—	.9	3.5

* ANOVA statistics not available due to low survival rates.

Mean separation (in columns) by Fisher's protected test.

^zMeans followed by same letter in a column are not significantly different.

Table 5.8. Shoot-plus-leaf dry weight (g) of prairie perennial seedlings transplanted from March, 1994, through November, 1994, on Indiana highway right-of-way sites. Values are means of 21 replicates.

Month	Shoot-Plus-Leaf Dry Weight (g)						
	Ratibida pinnata*	Andropogon gerardii	Echinacea pallida	Silene regia	Liatris pycnostachya	Veronicastrum virginicum	Aster novae- angliae
March	4.4 ^{NS}	5.2a ^Z	1.7 ^{NS}	.9de	---	.6c	8.5 ^{NS}
April	8.6	6.0a	.5	1.3de	---	1.4c	15.8
May	8.7	5.8a	---	1.6cde	.5b	1.3c	7.6
June	10.5	5.1a	5.2	1.8cd	2.0b	3.2ab	9.8
July	10.5	4.6a	6.6	2.2b	3.7a	3.4ab	9.9
August	8.5	2.6b	2.4	2.6b	2.9ab	4.2a	6.4
September	6.1	1.7b	6.6	2.7ab	1.3b	3.8a	6.3
October	4.7	1.0b	.3	.7e	.4b	.6c	2.6
November	5.7	1.8b	3.2	3.9a	2.0b	2.7b	5.8
PLSD 0.05	7.3	1.9	11.4	1.2	1.6	.8	7.1

Ratibida pinnata and Andropogon gerardii - 14 Replicates.

^ZMeans followed by same letter in a column are not significantly different.

Mean separation (in columns) by Fisher's protected test.

^{NS} ANOVA main effects were not significant for items in this column.

Table 5.9. Shoots-per-plant of prairie perennial seedlings installed on a constructed prairie, on a *Festuca arundinacea* site pre-treated with glyphosate, or mowed. Values are means of 63 replicates.

Treatment	Shoots-Per-Plant					
	Ratibida pinnata	Echinacea pallida	Silene regia	Liatris pycnostachya	Veronicastrum virginicum	Aster novae- angliae
Glyphosate	2.2a ^Z	3.0*	4.0a	1.0*	2.0a	4.7a
Mowed	.6b	2.5	2.5b	1.0	2.0a	3.2b
Prairie	---	1.3	3.0b	1.2	2.3a	2.7b
PSLD _{0.05}	.6	---	.8	---	.5	.8

*ANOVA statistics not available due to low survival rates.

^ZMeans followed by same letter in a column are not significantly different.

Mean separation (in columns) by Fisher's protected test.

Table 5.10. Shoots-per-plant of prairie perennial seedlings transplanted from March, 1994, through November, 1994, on Indiana highway right-of-way sites. Values are means of 21 replicates.

Month	Shoots-Per-Plant					
	<i>Ratibida</i> pinnata*	<i>Echinacea</i> pallida	<i>Silene regia</i>	<i>Liatris</i> pycnostachya	<i>Veronicastrum</i> virginicum	<i>Aster novae-</i> angliae
March	1.0 ^{NS}	3.0 ^{NS}	1.0d ^Z	— ^{NS}	1.6c	2.6c
April	2.3	0	2.6cd	—	2.1abc	4.4a
May	1.5	—	3.1bc	0	2.2abc	3.2abc
June	1.4	1.0	3.7ab	1.3	2.4abc	2.9bc
July	1.6	2.0	4.0ab	1.5	1.9bc	4.1ab
August	1.7	1.0	3.8ab	1.2	2.7ab	4.3a
September	1.0	2.0	4.5a	1.3	2.9a	3.9ab
October	1.1	2.5	1.3d	1.0	1.8c	1.8c
November	1.3	.8	3.6abc	1.0	1.7c	4.0ab
PLSD 0.05	1.4	5.3	1.1	1.5	.8	1.1

* *Ratibida pinnata* 14 replicates.

^ZMeans followed by same letter in a column are not significantly different.

Mean separation (in columns) by Fisher's protected test.

^{NS} ANOVA main effects were not significant for items in this column.

Table 5.11. Height (cm) of prairie perennial seedlings installed on a constructed prairie, on a *Festuca arundinacea* site pre-treated with glyphosate, or mowed. Values are means of 63 replicates.

Treatment	Height (cm)						
	Ratibida	Andropogon	Echinacea	Silene	Liatris	Veronicastrum	Aster novae-
	pinnata	gerardii	pallida	regia	pycnostachya	virginicum	angliae
Glyphosate	63.0a ^Z	33.0a	20.0*	25.1a	28.0*	25.6a	57.2a
Mowed	39.5b	30.9a	17.0	23.1a	20.0	27.5a	29.1b
Prairie	---	---	43.4	23.7a	23.8	28.2a	23.0c
PSLD _{0.05}	8.5	3.3	---	2.8	---	3.7	4.9

*ANOVA statistics not available due to low survival rates.

^ZMeans followed by same letter in a column are not significantly different.

Mean separation (in columns) by Fisher's protected test.

Table 5.12. Height (cm) of prairie perennial seedlings transplanted from March, 1994, through November, 1994, on Indiana highway right-of-way sites. Values are means of 21 replicates.

Month	Height (cm)						
	Ratibida pinnata*	Andropogon gerardii*	Echinacea pallida	Silene regia	Liatris pycnostachya	Veronicastrum virginicum	Aster novae- angliae
March	34.5c ^Z	38.4a	25.0bc	16.7de	—	18.7c	33.0c
April	38.4bc	38.1a	14.0c	21.7cd	—	21.4c	43.7a
May	47.4abc	30.1bc	—	21.3cd	18.0ab	19.7c	37.6abc
June	55.1ab	40.0a	61.7a	24.3bc	24.0a	29.0b	41.2ab
July	60.6a	35.3ab	50.3ab	26.5ab	24.8a	35.3ab	43.4a
August	63.7a	26.4cd	34.5bc	24.8abc	30.5a	38.1a	34.0bc
September	58.9a	21.3d	41.7ab	25.7ab	13.3b	31.9b	35.3abc
October	31.7c	24.0cd	16.0c	16.0e	20.0ab	18.3c	22.6d
November	61.5a	26.5cd	34.5bc	28.0a	26.0a	34.8ab	33.7bc
PLSD 0.05	18.5	8.5	22.3	3.9	8.6	5.7	9.0

* *Ratibida pinnata* and *Andropogon gerardii* - 14 replicates.

^ZMeans followed by same letter in a column are not significantly different.

Mean separation (in columns) by Fisher's protected test.

Table 5.13. Percentage survival of prairie perennial seedlings installed on a steep bank along an Indiana highway.

Species	Survival %	
	1994	1995
<i>Ratibida pinnata</i>	100	96
<i>Echinacea pallida</i>	98	89
<i>Schizachyrium scoparium</i>	82	79
<i>Liatris aspera</i>	62	33

Table 5.14. 1994 and 1995 survival of prairie perennial seedlings grown in media amended with hydrogels and installed on a steep bank along an Indiana highway right-of-way.

Treatment	Survival %							
	Schizachyrium		Ratibida		Liatris		Echinacea	
	scoparium		pinnata		aspera		pallida	
	1994	1995	1994	1995	1994	1995	1994	1995
Liqua-Gel	86	86	100	90	57	34	97	92
Terra-Sorb	97	89	100	97	55	26	97	89
GLK-8924	—	—	100	100	—	—	95	78
Control	75	70	100	97	71	40	100	90

Table 5.15. Effect of container depth on survival of prairie perennial seedlings installed on a steep bank along an Indiana highway right-of-way.

Container Depth	Survival %							
	Schizachyrium		Ratibida		Liatris		Echinacea	
	scoparium		pinnata		aspera		pallida	
	1994	1995	1994	1995	1994	1995	1994	1995
13cm	84	83	100	96	56	26	97	85
18cm	81	81	100	96	67	41	98	93

Table 5.16. The effect of hydrogel amendments on plant height of prairie perennial seedlings installed on a steep bank along an Indiana highway right-of-way. Values are means of 15 replicates.

Treatment	Height (cm)							
	Schizachyrium		Ratibida		Liatris		Echinacea	
	scoparium		pinnata		aspera		pallida	
	1994	1995	1994	1995	1994	1995	1994	1995
Liqua-Gel	16.9b	31.7a	21.8a	50.1ab	5.0a	27.9a	14.6a	45.7a
Terra-Sorb	20.6a	31.3a	22.4a	55.5a	4.4a	26.6a	17.2a	45.0a
GLK-8924	—	—	21.1a	41.1b	—	—	13.1b	31.6b
Control	26.0a	29.4a	21.6a	54.9a	6.1a	23.4a	14.5a	44.7a
PSLD _{0.0}	10.7	5.7	1.9	9.7	2.4	8.7	2.4	11.4

Mean separation (in columns for each species) by Fishers protected test.

Table 5.17. Effect of hydrogel amendment on flower shoots-per-plant of *Ratibida pinnata* seedlings planted on a steep bank along an Indiana highway right-of-way. Values are means of 15 replicates.

Treatment	Flower Shoots-Per-Plant
Liqua-Gel	1.0ab
Terra-Sorb	1.2a
GLK-8924	0.65b
Control	1.3a
PLSD ≤ 0.05	.40

Mean separation by Fishers protected test.

Table 5.18. The effect of container depth on shoots-per-plant (1994) and flower shoots-per-plant (1995) on prairie perennial seedlings planted on a steep bank along an Indiana highway right-of-way. Values are means of 15 replicates.

Container Depth	Shoots Per Plant / Flower Shoots Per Plant					
	Ratibida		Liatris		Echinacea	
	pinnata		aspera		pallida	
	1994	1995	1994	1995	1994	1995
13cm	10.6a ^z	.86b	4.0a	.27a	5.8b	.8a
18cm	11.7a	1.2a	5.3a	.31a	7.2a	1.1a
PSLD _{0.05}	1.6	.3	2.2	.36	1.1	.65

^zMean separation (in columns for each species) by Fishers protected test.

Table 5.19. The effect of container depth on 1995 average shoot-plus-leaf dry weight of prairie perennial seedlings planted on a steep bank along an Indiana highway right-of-way. Values are means of 15 replicates.

Container Depth	Shoot-Plus-Leaf Dry Weight (g)			
	Schizachyrium	Ratibida pinnata	Liatris aspera	Echinacea pallida
	scoparium			
13cm	7.2 a	3.3b	1.6a	4.9b
18cm	7.9a	5.0a	1.7a	8.7a
PSLD _{0.05}	2.5	.8	.9	2.0

Mean separation (in columns for each species) by Fishers protected test.

Table 5.20. August, 1994 shoots-per-plant of VAM inoculated or non-inoculated *Ratibida pinnata* and *Echinacea pallida* seedlings installed on a highway right-of-way. Values are means of 15 replicates.

Treatment	Shoots-Per-Plant	
	<i>Echinacea pallida</i>	<i>Ratibida pinnata</i>
Non-Inoculated	8.1a	^z 12.2b
<u><i>Glomus interadices</i></u>	7.9a	16.8a
<u><i>Gigaspora margarita</i></u>	6.4a	19.3a
Ambia-Talbot	—	16.5a
VAM Cocktail	5.4a	19.5a
PLSD $p < 0.05$	3.9	3.9

^zMean separation in columns by Fisher's protected test.

Items in columns with the same letter are not significant.

Table 5.21. 1994 height (cm) of VAM inoculated or non-inoculated *Ratibida pinnata* and *Echinacea pallida* seedlings installed on a highway right-of-way. Values are means of 15 replicates.

Treatment	Height (cm)	
	<i>Echinacea pallida</i>	<i>Ratibida pinnata</i>
Non-Inoculated	14.6 ^{NS}	22.4 ^{NS}
<u><i>Glomus interadices</i></u>	13.2	22.1
<u><i>Gigaspora margarita</i></u>	11.5	24.4
Ambia-Talbot	—	20.7
VAM Cocktail	11.5	22.3

^{NS} No significant ANOVA main effect for treatment for either species.

Table 5.22. 1995 overall survival of prairie perennial seedlings installed on a highway right-of-way.

Survival %	
Ratibida pinnata	100
Echinacea pallida	65
Liatris pycnostachya	24
Phlox pilosa	100

Table 5.23. 1995 height (cm) of VAM inoculated or non-inoculated prairie perennial seedlings installed on a highway right-of-way. Values are means of 15 replicates.

Treatment	Height (cm)			
	Echinaca pallida	Liatris pyc.	Ratibida pinnata	Phlox pilosa
Ambia - Talbot	---	54.1 ^{NS}	131.3 ^{NS}	29.7 ^{NS}
Gigaspora margarita	62.5 ^{NS}	55.0	138.8	29.2
Glomus interadicies	63.4	47.0	137.0	30.2
Cocktail	92.5	41.5	134.3	30.4
Non - inoculated	75.8	53.2	135.5	31.6

^{NS} No significant ANOVA main effect.

Table 5.24. 1995 shoots-per-plant of VAM inoculated or non-inoculated prairie perennial seedlings installed on a highway right-of-way. Values are means of 15 replicates.

Treatment	Shoots-per-plant			
	Echinace a pallida	Liatris pyc.	Ratibida pinnata	Phlox pilosa
Ambia - Talbot	—	1.0 ^{NS}	43.4ab ^Z	8.9 ^{NS}
Gigaspora margarita	3.1 ^{NS}	1.0	50.4a	12.7
Glomus interadices	2.9	1.5	41.7ab	7.9
Cocktail	2.1	1.0	45.2ab	10.4
Non - inoculated	2.7	2.2	37.4b	11.6

^{NS} No significant ANOVA main effect.

^ZMean separation in column by Fisher's protected test. PSLD=12.0

Table 5.25. 1995 shoot-plus-leaf dry weight (g) of VAM inoculated or non-inoculated prairie perennial seedlings installed on a highway right-of-way. Values are means of 15 replicates.

Treatment	Dry Weight (g)			
	Echinace a pallida	Liatris pyc.	Ratibida pinnata	Phlox pilosa
Ambia - Talbot	—	5.5 ^{NS}	260.8 ^{NS}	6.9 ^{NS}
Gigaspora margarita	22.4 ^{NS}	—	322.9	9.0
Glomus interadicies	21.7	6.2	309.6	8.1
Cocktail	20.7	4.8	287.8	9.4
Non - inoculated	18.7	9.6	272.8	7.2

^{NS} No significant ANOVA main effect for treatment.

Table 5.26. Mean infection percentages of VAM on prairie seedling roots one year after installation on an Indiana highway right-of-way.

Treatment	Mean Infection %			
	Echinacea pallida	Liatris pyc.	Ratibida pinnata	Phlox pilosa
Ambia - Talbot	—	52	50	42
Gigaspora margarita	48	60	66	60
Glomus interadicies	44	46	54	45
Cocktail	42	20	50	52
Non - inoculated	32	40	68	50

CHAPTER 6

COST ANALYSIS

6.1. Problem Statement

As a result of the experiments assessing appropriate wildflower species and establishment methods for Indiana highways, several possible alternative roadside vegetation management strategies have been suggested. Decisions concerning adoption of these management strategies will be based, in part, on the economic feasibility of the various alternatives. Thus, it is necessary to predict the implementation costs associated with the strategy options.

6.2. Objectives

The current vegetation management program for Indiana highways emphasizes mowed turfgrasses. The wildflower alternatives suggested in this study include direct seeding of "garden" and native prairie species, as well as transplanting of native prairie species. This analysis compares estimated costs associated with the current practice of turfgrass establishment and maintenance, "garden" wildflower establishment and maintenance (including regular renovation), and native prairie grass and forb establishment and maintenance.

6.3. Work Plan

Several implementation scenarios are outlined in this cost analysis based on the results of the experiments included in this study. Each implementation scenario is evaluated as to the materials, equipment, and labor costs involved for both establishment and management on an annual, per acre basis. The cost figures presented are a combination of "in-house" costs for work to be performed using existing INDOT staff and equipment, and recently reported costs for work to be performed using private contractors. The "in-house" cost figures were provided by Mr. Don Bickel, Landscape Supervisor, Crawfordsville District, INDOT. Private contractor cost figures were provided by Spence Landscaping & Nursery, Inc., Muncie, IN, and Slusser's Green Thumb, Inc., Logansport, IN. Seed cost figures were provided by Clyde Robin Seed Co., Hayward, CA, Wildseed Farms, Eagle Lake, TX, Applewood Seed Co., Arvada, CO, Sharp Bros. Seed Co., Healy, KS, Prairie Nursery, Westfield, WI, Prairie Moon Nursery, Winona, MN, and Prairie Ridge Nursery, Mt. Horeb, WI. Seedling production and transplanting cost figures were provided by Stuewe & Sons, Inc., Corvallis, OR, the Ohio Cooperative Extension Service, Columbus, OH, the Illinois Department of Transportation, Schaumburg, IL, and the Lone Peak State Tree Nursery, Draper, UT. While this analysis may not provide a totally accurate picture of the predicted implementation costs, it is the best estimate available at the present time.

6.4. Analysis Of Data

6.4.1 Roadside Turfgrass Establishment

The costs for the current practices of roadside turfgrass establishment and management provide the baseline for comparison with wildflower alternatives. There are two methods employed in roadside turfgrass establishment. The most common is direct seeding (Table 6.1); the other is installation of sod (Table 6.2). Much of the roadside turfgrass establishment and management in Indiana is carried out by private contractors, thus an "in-house" cost estimate is not included here. The estimates for direct seeding and sod installation of turfgrass on a previously graded site reflect average costs from 1994 INDOT bid records as reported by Mr. Don Bickel. All costs include mark-ups for overhead, materials and labor, and profit margin. All costs are on a per unit basis except for "Mobilization" which is a fixed cost per contract.

**Table 6.1: Costs of establishment for direct seeding of turfgrass
by contract**

Item	Cost Per Unit	Units Per Acre	Subtotal
Mobilization *	\$440.00/contract	NA	\$440.00
Fertilizer	\$420.00/ton	800 lbs./acre	\$168.00
Seed Mix R **	\$2.75/lb.	170 lbs./acre	\$467.50
Mulch	\$330.00/ton	2 tons/acre	\$660.00
Total Estimated Cost Per Acre			\$1735.50

* As reported by Mr. Tom Slusser (Slusser's Green Thumb, Inc.), "Mobilization" costs affect the "Total Estimated Cost Per Acre" as the quantity of acres increases. Table 6.1 reports the "Total Estimated Cost Per Acre" for one acre only at a "Mobilization" cost of \$440.00. If the number of acres were to be increased to 20, the "Mobilization" cost would be divided by 20 and the "Total Estimated Cost Per Acre" would be reduced to \$1,317.50. It should be noted that "Mobilization" costs vary by contractor, by location, and by project, thereby affecting the "Total Estimated Cost Per Acre" for each individual project. As an example, a "Mobilization" cost of \$440.00 is representative of the average costs involved with jobs that are performed within a 30-40 mile radius of the contractors base of operations. As the distance travelled increases so does the "Mobilization" cost.

** The estimates in Table 6.1 report the costs for using a standard, State specified, general purpose, roadside seed mixture designated as Seed Mix R. Seed Mix R consists of 95 lbs. tall fescue, 65 lbs. perennial rye, and 10 lbs. creeping red fescue for a total of 170 lbs. per acre.

Table 6.2: Costs of establishment for sod installation of turfgrass by contract

Item	Cost Per Unit	Units Per Acre	Subtotal
Mobilization	\$440.00/contract	NA	\$440.00
Fertilizer	\$420.00/ton	800 lbs./acre	\$168.00
Turfgrass Sod *	\$2.30/sq. yd.	4,840 sq. yds./acre	\$11,132.00
Total Estimated Cost Per Acre			\$11,740.00

* As reported by Mr. Tom Slusser, the estimate for "Turfgrass Sod" includes 4 weeks of sod maintenance, i.e. watering, pinning, pegging, etc.. The State also requires a separate bid item for water not included in this analysis. This item is found on most projects using sod and is bid per one thousand gallons of water. The usual bid prices range from \$2.00-5.00 per one thousand gallons of water. This item is only used after the four weeks of sod maintenance has expired and the sod requires additional maintenance due to detrimental weather conditions. This item is extremely project specific and thus was not included in this analysis.

6.4.2. Roadside Turfgrass Management

Annual management practices for turfgrass plantings typically include mowing to a height of 6" or less several times during the growing season. For this estimate (Table 6.3), three mowings per growing season have been assumed. Turfgrass plantings are also managed with a blanket application of broadleaf herbicide every three years. In addition, spot spraying of herbicides is used for control of specific problem weeds. However, this activity is sporadic and difficult to quantify and is omitted from this analysis. The estimates for mowing and herbicide management reflect average costs from 1994 INDOT bid records as reported by Mr. Don Bickel. All costs include mark-ups for overhead, materials and labor, and profit margin.

Table 6.3: Annual management costs for roadside turfgrass by contract

Item	Cost	Frequency	Subtotal
Mowing	\$22.00/acre	3 Times Per Year	\$66.00/acre/year
Herbicide Application	\$33.40/acre	Every 3 Years	\$11.13/acre/year
Total Estimated Cost Per Acre Per Year			\$77.13

6.4.3. Direct Seeding Establishment Of "Garden" Wildflowers

"Garden" wildflower plantings are one alternative to roadside turfgrasses. As previously noted, "garden" wildflowers are typically cultivated annuals, biennials, or perennials which are most frequently used in urban garden settings and grown in a "wild" manner (usually in mixes which attempt to emulate natural meadow or prairie environments). "Garden" wildflower species may be either native or introduced. They have quick establishment periods and display abundant color the year of planting. Many "garden" species will readily self-sow after the first year, but typically will need to be re-established after the second year, thus increasing their long-term cost.

Seed costs for "garden" wildflower species are the obvious starting point for consideration of this roadside vegetation management strategy (Table 6.4). Seed costs from 1994 catalogs were provided by three selected seed nurseries. These nurseries were selected on the basis of their reputation and standing within the industry, and the overall quality and availability of their seed. The 11 "garden" wildflower species listed were selected on the basis of their aesthetic qualities, hardiness, ability to self-sow, and seasonal appeal. The "Average Cost" column reflects the average cost per species from the selected nurseries. The "Total Average Cost Per Pound" is the average cost of the 11 selected species and represents an estimate of the average cost per pound for INDOT to acquire "garden" wildflower seed. The average number of seeds per pound is included for each species.

Table 6.4: Seed costs for selected "garden" wildflower species

Species Common Name (Seeds Per Pound)	Clyde Robin Seed Company	Wildseed Farms	Applewood Seed Company	Average Cost
Common Cosmos (80,800)	\$14.00	\$22.50	\$19.00	\$18.50
Yellow Cosmos (61,000)	\$16.00	\$25.00	\$19.00	\$20.00
Plains Coreopsis (1,666,000)	\$18.00	\$20.00	\$22.00	\$20.00
Rocket Larkspur (142,000)	NA	\$24.00	\$24.00	\$24.00
Mealy-Cup Sage (368,000)	NA	\$92.00	\$75.00	\$83.50
Corn Poppy (3,179,000)	\$16.00	\$20.00	\$20.00	\$18.67
Black-Eyed Susan (1,697,000)	\$16.00	\$25.00	\$20.00	\$20.33
Blanket Flower (223,300)	\$30.00	\$20.00	\$25.00	\$25.00
Scarlet Sage (277,000)	\$47.00	\$68.00	\$44.00	\$53.00
Dame's Rocket (246,000)	\$12.00	\$19.00	\$12.00	\$14.33
Cornflower (89,000)	\$7.00	\$8.50	\$6.00	\$7.17
Total Average Cost Per Pound				\$27.68

The recommended establishment method for "garden" wildflowers includes several steps. First is the application of a non-selective, non-residual herbicide to remove the existing vegetative cover from the site. Site preparation using deep tillage following the herbicide application and shallow tillage just prior to seeding is next. The deep tillage is recommended to tear up the dead plant material and turn it under. Also dormant weed seed is expected to be disturbed and brought to the surface to germinate. The shallow tilling prior to seeding will destroy any weed seedlings that have germinated. The final step is to seed the site. For purposes of this analysis a Truax seed drill is proposed due to its flexibility with different seed types and the fact that several INDOT districts already own them. The estimated costs associated with these procedures are detailed in Table 6.5. All figures are "in-house" costs for existing INDOT staff and equipment as reported by Mr. Don Bickel. It should be noted that the procedures outlined in this analysis are a combination of the experimental results of this study as well as the personal experience of Mr. Don Bickel. Mr. Bickel has successfully established and maintained "garden" wildflower plantings in the Crawfordsville District. This estimate assumes that existing turfgrass plantings will be converted to "garden" wildflower plantings.

Table 6.5: Costs of establishment for direct seeding of "garden" wildflowers

Procedure	Cost of Materials	Equipment Operating Costs	Labor Costs	Hours Required	Subtotal
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Non-selective, Non-residual Herbicide Application	3 qts. Round-Up™ @ \$40.00/gal.	Truck/Trailer @ \$12.00/hr. Tractor/Sprayer @ \$12.00/hr.	1 INDOT Employee @ \$18.00/hr.		
	\$30.00	+	[(\$24.00	+	\$18.00) x 1.75] = \$103.50
Tilling (Deep Till Following Herbicide Application, Shallow Till Prior to Seeding)	NA	Truck/Trailer @ \$12.00/hr. Tractor/Tiller @ \$12.00/hr.	2 INDOT Employees @ \$18.00/hr.		
			[(\$24.00	+	\$36.00) x 5.5] = \$330.00
Seeding *	10 lbs. Garden Wildflower Seed @ \$27.68/lb.	Truck/Trailer @ \$12.00/hr. Tractor/Seeder @ \$12.00/hr.	3 INDOT Employees @ \$18.00/hr.		
	\$276.80	+	[(\$24.00	+	\$54.00) x 3.75] = \$569.30
Total Estimated Cost Per Acre					\$1002.80

* It should be noted that a seeding rate of 10 lbs. per acre represents an average seeding rate. There are numerous possibilities for different seeding rates and "garden" wildflower mixtures. According to Wildseed Farms and Applewood Seed Co., a wildflower seed mixture of this nature (consisting of annuals, biennials, and perennials of various origins) can be seeded at rates ranging from 5-22 lbs. per acre depending upon the species used and the results desired. Experimentation in this study has focused on individual species performance only, thus no "garden" wildflower mixtures can be recommended based upon experimental results at this time. This analysis assumes a 10 lb. mixture of the selected species at the average cost per pound outlined in Table 6.4.

6.4.5. "Garden" Wildflower Management

Our recommended management regime for "garden" wildflowers includes the use of a grass selective herbicide after the "garden" seedlings begin to appear to reduce competition with unwanted annual and perennial grasses. Mowing is necessary 1 to 2 times annually; once in early to mid-summer to clean up spring flowering plots and once in late summer or early fall to clean up summer flowering plots. Because the majority of "garden" wildflower species are annuals, re-seeding is necessary at least every third year to maintain the quality of the planting. The re-seeding cost is simply one-third of the total estimated establishment cost per acre from Table 6.5. The costs

associated with these procedures are detailed in Table 6.6. All figures are "in-house" costs for existing INDOT staff and equipment as reported by Mr. Don Bickel.

Table 6.6: Annual management costs for "garden" wildflowers

Procedure	Cost of Materials	Equipment Operating Costs	Labor Costs	Hours Required	Subtotal
Grass-selective Herbicide Application	3 qts. Fusilade @ \$60.00/gal.	Truck/Trailer @ \$12.00/hr. Tractor/Sprayer @ \$12.00/hr.	1 INDOT Employee @ \$18.00/hr.		
	\$45.00	+	[(\$24.00	+	\$18.00) x 1.75] =
Annual Mowing	Cost Breakdown Unavailable, Private Mowing Crews Are Typically Contracted by INDOT, Estimate Reflects Average Cost From 1994 INDOT Bid Records				\$22.00
Re-seeding	Total Estimated Establishment Cost Per Acre From Table 5 \$1002.80 / 3 =				\$334.27
Total Estimated Cost Per Acre Per Year					\$474.77

6.4.6. Direct Seeding Establishment of Native Prairie Grasses and Forbs.

Native prairie grass and forb plantings provide another alternative to roadside turfgrasses. Experimentation in this study has involved two direct seeding methods, two transplanting methods, and two management methods for the establishment and maintenance of prairie plantings. The establishment methods assume that existing turfgrass right-of-ways will be converted to prairie plantings, thus site preparation costs are included.

Seed costs are the starting point for consideration of the prairie establishment methods. Grass seed (Table 6.7) and forb seed (Table 6.8) are considered separately and individually by species. The grass and forb seed costs are from 1994 catalogs provided by 4 different producers. These seed nurseries were selected for their reputation and standing within the industry. The grass species were selected based on their dominance in the original prairie ecosystem and nursery availability. They are representative of the most commonly used species for prairie restoration and establishment. The forb species were selected because they are natives of Indiana, and because of their aesthetic qualities, period of bloom, plant size, and hardiness. In both Tables 6.7 and 6.8 the "Average Cost" column reflects the average cost per species from the selected nurseries. The "Total Average Cost Per Pound" is the average cost of the selected species and represents an estimate of the average cost per pound for INDOT to acquire native prairie grass and forb seed. The average number of seeds per pound is included for most species. Seed costs are used in computations of direct seeding and in estimating the cost of producing plug transplants elsewhere in the analysis.

Table 6.7: Seed costs for selected native prairie grass species

Species (Seeds Per Pound)	Sharp Brothers	Prairie Nursery	Prairie Moon Nursery	Prairie Ridge Nursery	Average Cost
Little Bluestem (140,800)	\$7.25	\$32.00	\$20.00	\$35.00	\$23.56
Side Oats Grama (128,000)	\$7.25	\$40.00	\$16.00	\$40.00	\$25.81
Indian Grass (132,000)	\$5.88	\$20.00	\$13.00	\$30.00	\$17.22
Big Bluestem (131,200)	\$5.25	\$30.00	\$16.00	\$30.00	\$20.31
Switch Grass (288,000)	\$4.38	\$15.00	\$6.00	\$35.00	\$15.10
Total Average Cost Per Pound					\$20.40

Table 6.8: Seed costs for selected native prairie forb species

Species (Seeds Per Pound)	Prairie Nursery	Prairie Moon Nursery	Prairie Ridge Nursery	Average Cost
Royal Catchfly (448,000)	\$1500.00	\$600.00	NA	\$1050.00
New England Aster (1,120,000)	\$750.00	\$150.00	\$200.00	\$366.67
Prairie Coreopsis (NA)	NA	\$450.00	\$640.00	\$545.00
Tall Coreopsis (184,000)	NA	\$240.00	NA	\$240.00
Pale Purple Coneflower (105,600)	\$300.00	\$180.00	\$175.00	\$218.33
Rattlesnake Master (128,000)	\$225.00	\$75.00	\$200.00	\$166.67
Rough Blazing Star (216,000)	\$600.00	\$120.00	\$150.00	\$290.00
Prairie Blazing Star (192,000)	\$225.00	\$120.00	\$150.00	\$165.00
Wild Bergamot (1,248,000)	\$300.00	\$150.00	\$325.00	\$258.33
Wild Quinine (108,800)	\$375.00	\$120.00	\$300.00	\$265.00
Large-Flowered Beardtongue (176,000)	NA	\$150.00	\$400.00	\$275.00
Prairie Phlox (NA)	NA	\$1920.00	NA	\$1920.00
Yellow Coneflower (432,000)	\$75.00	\$90.00	\$100.00	\$265.00
Culver's Root (12,000,000)	\$750.00	\$480.00	\$500.00	\$576.67
Butterfly Milkweed (56,000)	\$900.00	\$320.00	\$300.00	\$506.67
Total Average Cost Per Pound				\$473.89

Two possible native prairie seed mixtures are proposed for highway plantings (Table 6.9) based on direct seeding experiments in this study. The forb species selected had the highest germination and establishment rates from the species list in Table 6.8. The grass species were selected based on their height characteristics and subsequent compatibility with the forb species for maximum flower visibility. The first mix is a grass dominant mixture with a 60% grass, 40% forb composition. The second mix is a forb dominant mixture with an 80% forb, 20% grass composition.

A seeding rate of 10 pounds per acre is recommended based on the following:

- 15 live seeds per square foot is recommended for adequate coverage.
- A mean germination percentage of ~33% has been observed in this study for the forb species.
- There are 43,560 square feet in one acre.
- $15 / .33 * 43,560 = 1,980,000$ seeds (rounded up to 2,000,000 seeds).
- An average of 2,000,000 seeds per 10 pounds has been calculated, thus the rate of 10 pounds of seed per acre.

Table 6.9: Estimated costs for proposed native prairie seed mixtures

Species	Average Cost/Pound	Grass Dominant Mix		Forb Dominant Mix	
		Seed Weight	Seed Cost	Seed Weight	Seed Cost
Little Bluestem	\$23.56	3.0 lbs.	\$70.68	0.7 lbs.	\$16.49
Side Oats Grama	\$25.81	1.0 lb.	\$25.81	0.6 lbs.	\$15.49
Indian Grass	\$17.22	2.0 lbs.	\$34.44	0.7 lbs.	\$12.05
New England Aster	\$366.67	0.5 lbs.	\$183.34	1.5 lbs.	\$550.01
Tall Coreopsis	\$240.00	0.5 lbs.	\$120.00	1.5 lbs.	\$360.00
Pale Purple Coneflower	\$218.33	1.2 lbs.	\$262.00	2.0 lbs.	\$436.67
Wild Bergamot	\$258.33	0.6 lbs.	\$155.00	1.0 lb.	\$258.33
Yellow Coneflower	\$265.00	1.2 lbs.	\$318.00	2.0 lbs.	\$530.00
Total Estimated Costs Per Acre:		10 lbs. @ \$1169.27 grass mix		10 lbs. @ \$2179.04 forb mix	

Two alternative seeding procedures are proposed for prairie plantings (Table 6.10) based on establishment experiments conducted for this study. The steps are the same as for "garden" wildflower establishment (herbicide application, tilling, seeding). The methods differ only in the inclusion of tillage in Method One and its omission (drilling of seed into undisturbed soil) in Method Two.

Table 6.10: Establishment costs for two seeding methods for native prairie seed mixtures*

Procedure	Cost of Materials	Equipment Operating Costs	Labor Costs	Hours Required	Subtotal
Non-selective, Non-residual Herbicide Application	3 qts. Round-Up™ @ \$40.00/gal.	Truck/Trailer @ \$12.00/hr. Tractor/Sprayer @ \$12.00/hr.	1 INDOT Employee @ \$18.00/hr.		
	\$30.00 +	[(\$24.00 +	\$18.00) x	1.75] =	\$103.50
Tilling (Deep Till Following Herbicide Application, Shallow Till Prior to Seeding)	NA	Truck/Trailer @ \$12.00/hr. Tractor/Tiller @ \$12.00/hr.	2 INDOT Employees @ \$18.00/hr.		<i>This cost is omitted in Method Two.</i>
		[(\$24.00 +	\$36.00) x	5.5] =	\$330.00
Seeding	5 lbs. Annual Ryegrass/acre (Cover Crop) @ \$.60/lb. Seed Mixes @ \$1169.27 for Grass Mix/acre @ \$2179.04 for Forb Mix/acre \$1172.27 or \$2182.04 +	Truck/Trailer @ \$12.00/hr. Tractor/Seeder @ \$12.00/hr.	3 INDOT Employees @ \$18.00/hr.		
		[(\$24.00 +	\$54.00) x	3.75] =	\$1464.77 or \$2471.54

Total Estimated Costs Per Acre:

Method One (with tillage)	
Grass Mix	\$1898.27
Forb Mix	\$2905.04
Method Two (without tillage)	
Grass Mix	\$1568.27
Forb Mix	\$2575.04

* As reported by Mr. Kevin Tungesvick, Spence Landscaping & Nursery, Inc. quotes a price of ~\$2,000/acre to seed a mixture similar to the 60/40 grass dominant mixture proposed in this study. Spence also quotes a price of ~\$2,400/acre to seed a mixture similar to the 80/20 forb dominant mixture. These quotes include all site preparation, materials, labor, and overhead costs.

6.4.7. Production and Transplanting Establishment of Native Prairie Grasses and Forbs

Plug transplanting is a simple, successful method to install prairie plant seedlings. Table 6.11 outlines an estimate for greenhouse production of prairie plugs. All costs reflect a one time use of the plug racks and plug cells, though both items are reusable. Both the plug racks and plug cells are manufactured by Stuewe & Sons, Inc., a supplier of growing containers for the forest products industry. The assumed germination medium is 40% sphagnum peat, 40% perlite, and 20% topsoil (the standard greenhouse mixture of the Purdue University Horticulture Department). The seed cost is an average of both prairie grass and forb seed costs (Tables 6.7 and 6.8) and is calculated using the average number of seeds per pound and the average price per pound. Labor, daily care, and overhead costs are based on known values from the greenhouse industry (Ohio Cooperative Extension Service, Bulletin FP-763, "Tips on Growing Bedding Plants"). Wholesale and retail profit margins are included so the estimate will more closely reflect private contractor prices.

**Table 6.11: Estimated costs of production for plug transplants of native prairie
grasses and forbs**

Item	Cost
1 RLC-7 Super "Stubby" Plug Cell	\$.07
• cost per case = \$93.92	
• cells per case = 1,320	
1 Plug Cell Unit Per RL 98 Plug Cell Rack	\$.06
• cost per case = \$50.58	
• racks per case = 8	
• cost per rack = \$6.32	
• units per rack = 98	
1 Unit Planting Mix Per Plug Cell	\$.007
• cost per cubic inch = \$.001	
• cubic inches per plug cell = 7	
4 Seeds Per Plug Cell	\$.002
• cost per seed = \$.0005	
1 Unit Labor Per Plug Cell	\$.005
(fill plug cells, sow seed, place plug rack)	
• cost per rack = \$.46	
• plug cells per rack = 98	
1 Unit Maintenance Per Plug Cell	\$.002
(watering, clipping, fertilizing)	
• cost per rack = \$.23	
• plug cells per rack = 98	
1 Unit Overhead Per Plug Cell	\$.04
• cost per square foot per week = \$.19	
• square feet per rack = 2	
• production time = 10 weeks	
• overhead cost per rack = \$3.80	
• plug cells per rack = 98	
Total Cost Per Plug Cell	\$.19
Add 50% Wholesale Profit Margin	\$.38
Add 50% Retail Profit Margin	\$.76

* As reported by Doug Spence and Jim Savage of Spence Landscaping & Nursery Inc., the above estimate is in general agreement with production costs for the above mentioned establishment. Their estimates assume germination of prairie seedlings in flats followed by transplanting to the Stuewe plug cells. Our estimates assume germination of the prairie seedlings directly in the plug cells, thus eliminating the transplanting stage. In all other aspects the production costs are similar.

Two transplanting methods have potential merit for use with plug transplants. One employs a tractor-drawn mechanized transplanter (as manufactured by Holland, Inc., etc.) (Table 6.12). This method is most suitable for flat or gently rolling terrain. The other involves manual labor done with a crew using steel-tipped planting dibbles such as those available from Stuewe & Sons, Inc. (Table 6.13). Hand transplanting is a necessary alternative where steepness of slope prevents equipment access, or it may be the preferred alternative when volunteer labor is available.

Table 6.12: Mechanized installation costs for plugs of native prairie grasses and forbs

Procedure	Cost of Materials	Equipment Operating Costs	Labor Costs	Hours Required	Subtotal
Non-selective, Non-residual Herbicide Application	3 qts. Round-Up™ @ \$40.00/gal.	Truck/Trailer @ \$12.00/hr. Tractor/Sprayer @ \$12.00/hr.	1 INDOT Employee @ \$18.00/hr.		
	\$30.00 +	[(\$24.00 +	\$18.00) x	1.75] =	\$103.50
Tilling (Deep Till Following Herbicide Application)	NA	Truck/Trailer @ \$12.00/hr. Tractor/Tiller @ \$12.00/hr.	2 INDOT Employees @ \$18.00/hr.		
		[(\$24.00 +	\$36.00) x	3.75] =	\$225.00
Planting* (Plant Plugs Using Mechanized Trans-planter)	10,000 Plugs @ \$.38/plug	Truck/Trailer @ \$12.00/hr. Tractor/Trans-planter @ \$12.00/hr.	3 INDOT Employees @ \$18.00/hr.		
	\$3800.00 +	[(\$24.00 +	\$54.00) x	50] =	\$7700.00
Total Estimated Cost Per Acre (Mechanical Transpl.)					\$8028.50

* The cost figures for mechanical installation of native prairie grass and forb plugs are those reported by Charles Gouveia, District One Landscape Architect, Illinois Department of Transportation. According to Mr. Gouveia, an experienced operator, using an unmodified "Groundbreaker" tree seedling planting machine, can plant over 200 plants per hour. An

ideal crew would consist of a tractor driver, a plantsman, and a crew member to remove seedlings from containers and keep the plantsman supplied with plants. These cost figures are the only available estimate for mechanized transplanting known to us at this time. The cost can be manipulated to some degree. If, for example, 5 machines and 15 employees were used, the job could be completed in 8 hours at a cost of \$7248.50.

Table 6.13: Manual labor installation costs for plugs of native prairie grasses and forbs

Procedure	Cost of Materials	Equipment Operating Costs	Labor Costs	Hours Required	Subtotal
Non-selective, Non-residual Herbicide Application	3 qts. Round-Up™ @ \$40.00/gal.	Truck/Trailer @ \$12.00/hr. Tractor/Sprayer @ \$12.00/hr.	1 INDOT Employee @ \$18.00/hr.		
	\$30.00 +	[(\$24.00 +	\$18.00) x	1.75] =	\$103.50
Tilling (Deep Till Following Herbicide Application)	NA	Truck/Trailer @ \$12.00/hr. Tractor/Tiller @ \$12.00/hr.	2 INDOT Employees @ \$18.00/hr.		
		[(\$24.00 +	\$36.00) x	3.75] =	\$225.00
Planting* (Plant Plugs Using Manual Planting Dibbles)	10,000 Plugs @ \$.38/plug	4 Trucks @ \$12.00/hr.	18 INDOT Employees @ \$18.00/hr.		
	\$3800.00 +	[(\$48.00 +	\$324.00) x	8] =	\$6776.00
Total Estimated Cost Per Acre (Hand Transpl.)					\$7104.50

* The cost figures for manual installation of native prairie grass and forb plugs are those reported by Glen Beagle (Director) and John Justin (Nursery Manager) of the Lone Peak State Tree Nursery. According to Mr. Beagle, an experienced 18 person crew can transplant 10,000 plugs per day given ideal planting conditions. The above mentioned facility uses the Stuewe & Sons plug cells and planting dibbles. The estimate assumes all equipment is already present and no initial costs are incorporated.

6.4.8. Native Prairie Wildflower Management

Two methods are suggested for management of prairie plantings (Table 6.14). The preferred approach is prescribed, controlled burning. An alternative when burn management is not feasible is mowing with conventional equipment. Mowing costs used in this estimate are average INDOT contract costs. Mowing is required once annually. Spring mowing is suggested to reduce dead vegetative cover to increase light penetration to the soil and the resulting soil warming. Prescribed burning is required once every three years.

Table 6.14: Annual management costs of prescribed burning or mowing management for native prairie grass and forb plantings

Procedure	Cost of Materials	Equipment Operating Costs	Labor Costs	Hours Required	Subtotal
Annual Fall Mowing	NA	Cost Breakdown Unavailable (Private mowing crews are typically contracted by INDOT, estimate reflects average cost from 1994 INDOT bid records.)			\$22.00
Triennial Burn	NA	2 Trucks @ \$12.00/hr.	3 INDOT Employees @ \$18.00/hr.		
		[(\$24.00	+ \$54.00)	x 1.75]/3=	\$39.00

6.5. Conclusions

Care should be taken in the interpretation of this analysis. All scenarios for wildflower program implementation are tentative at present until further refinements in methods, and confidence in results can be obtained. It should also be remembered that cost is but one criterion for measurement of success of a roadside vegetation management plan. For instance, the analysis shows garden wildflower plantings to be more cost-effective than turfgrasses or prairie plantings, even long-term. What the analysis does not consider is the issue of erosion control. Both turfgrasses and prairie plantings, due to their more permanent nature, are much better alternatives where erosion control is an issue.

The cost projections do indicate that several wildflower establishment and management strategies are cost competitive with conventional vegetation management as currently practiced by INDOT. These numbers support the further investigation into wildflowers and native plant communities for use on Indiana roadsides.

CHAPTER 7

RECOMMENDATIONS AND FUTURE RESEARCH NEEDS

7.1. Recommendations: Seed Quality

Seed quality should continue to be a concern for all purchasers of wildflower seed. It is impossible to recommend a single, or few, wildflower seed companies to INDOT as "best" sources of seed for future wildflower projects. Too much variability exists among all suppliers.

Several directions for INDOT are indicated by the study results.

1. Uniform state standards for wildflower seed testing and the reporting test results, similar to those that exist for horticultural and agronomic seeds, should be established and applied to companies that sell wildflower seed.
2. In the absence of such standards, every effort should be made to purchase seed from suppliers that voluntarily do report seed viability as Pure Live Seed (PLS).
3. In the absence of seed quality information from suppliers, INDOT should require seed lots to be used on highway projects be sampled and tested prior to their use, by the Indiana State Seed Testing Laboratory. This will allow an adjustment in the seeding rates as needed.
Testing is needed on all seed, for all projects, every year.
4. Initially, before any of the above is adopted, INDOT should use 75% germination rate for "garden" species, and 25% germination rate for prairie forb species, as the assumed viability level upon which to base computations for wildflower seeding rates.

7.1.1. Future Research Needs: Seed Quality

In order to allow widespread testing of many wildflower species, especially natives, it is critical that optimum, standardized germination protocols be developed. These protocols must include temperature, moisture, light, and seed pre-treatment (stratification) criteria. It will not be feasible to require seed producers to provide PLS data until such protocols are in place.

A great deal of research is needed in conjunction with wildflower producers to improve production and handling methods of wildflower seed to maximize its viability when it reaches the purchaser. While this work is probably beyond the scope of INDOT, it should be encouraged.

7.2. Recommendations: Direct Seeding - Garden Species

The primary goal of this study was to determine those species which had significant potential for successful direct seeding establishment on a variety of sites. While the data are often difficult to interpret conclusively, the following lists define what the authors believe to be the best species for INDOT use.

Recommended garden wildflower species for spring sowing:

For first-year best flowering:

Common Cosmos, *Cosmos bipinnatus* (pink flowers, large, any soils)

Yellow Cosmos, *Cosmos sulphureus* (yellow flowers, intermediate, any soils)

Cornflower, *Centaurea cyanus* (blue flowers, small, better soils)

For second-year best flowering:

Plains Coreopsis, *Coreopsis tinctoria* (yellow flowers, intermediate, poorer soils)

Black-eyed Susan, *Rudbeckia hirta* (yellow flowers, small, any soils)

Recommended species for fall sowing

For first-year best flowering:

Corn Poppy, *Papaver rhoeas* - red/pink/white flowers, intermediate, well-drained soils)

Rocket Larkspur, *Consolida ambigua* - blue/white flowers - any soils

Inconclusive results, but species deserving of future consideration

Blanket Flower, *Gaillardia pulchella* (yellow/red flowers, small, better soils)

Scarlet Sage, *Salvia coccinea* (red flowers, intermediate, better soils)

Mealy-cup Sage, *Salvia farinacea* (blue flowers, intermediate, better soils)

Our experimental results regarding planting methods suggest the following scenario will give satisfactory results with the above listed species. Existing vegetative cover should be eliminated with non-residual, non-selective herbicide such as glyphosate (Round-Up). Satisfactory seed placement with the Truax drill can be achieved with no preplant soil working. Seed placement depth is satisfactory at 1/4" or 1/2".

Observations of plant appearance and visual utility not directly a part of the experimental plan were made during the course of this study. Based on those observations, we recommend that, generally, masses of a single wildflower species be planted rather than mixes. Diversity should be achieved by the planting of multiple masses of different species in close proximity to one another, or successively along the right-of-way.

Design consideration should be given to the location of plantings so that visibility of a small-statured species is not hindered by proximity to a taller species. When plantings are to be located in the high speed part of right-of-way, dimensions of plantings should be maximized linearly so that relatively narrow bands of color are developed for a significant length of roadway, rather than large areas which pass by the driver's view too rapidly to be appreciated.

Color of any kind is a welcome relief from driving monotony, but flower visibility appears to be maximized with yellow, then pink flowers; it is minimized with blue flowers. Although we had some success with the blue flowered species Cornflower, *Centaurea cyanus* and Rocket Larkspur, *Consolida ambigua* (fall seeding only), these should be used primarily in slow speed areas or in extremely large quantity to have significant impact.

7.2.1. Future Research Needs: Direct Seeding - Garden Species

Further work is needed to determine, conclusively, which species are suitable for spring seeding and which are suitable for fall sowing. This current study involved only spring sowing of garden species, but additional preliminary studies suggest that a complete exploration of spring versus fall planting for garden species is warranted.

Weed management needs to be addressed in future research. Herbicide usage is a potentially viable alternative if plantings are limited to one of very few species with similar herbicide tolerances.

Additional research would be beneficial to investigate a wider range of potential garden species for wildflower use. The seed industry continues to expand and additional species are constantly becoming available for consideration.

7.3. Recommendations: Direct Seeding - Prairie Species

The primary goal of this study was to determine those prairie species which had significant potential for successful direct seeding establishment on a variety of sites. These data, too, are often difficult to interpret conclusively, but the following lists define the authors views concerning the best species for INDOT use.

Recommended prairie wildflower species:

<i>Asclepias tuberosa</i>	Butterfly Milkweed
<i>Aster novae-angliae</i>	New England Aster
<i>Echinacea pallida</i>	Pale-purple Coneflower
<i>Monarda fistulosa</i>	Wild Bergamot
<i>Ratibida pinnata</i>	Gray-headed Coneflower
<i>Vernonia fasciculata</i>	Ironweed

Inconsistent results, but species deserving of consideration and future research

<i>Eryngium yuccifolium</i>	Rattlesnake Master
<i>Parthenium integrifolium</i>	Wild Quinine
<i>Phlox pilosa</i>	Prairie Phlox

Our experimental results regarding planting methods suggest the following scenario. Existing vegetative cover should be eliminated with non-residual, non-selective herbicide such as glyphosate (Round-Up). However, weed pressure following vegetation removal may be a problem. Cover cropping may be a good alternative, but that is beyond the scope of this present study. Satisfactory seed placement with the Truax drill can be achieved with no preplant soil working. Seed placement depth is satisfactory at 1/4" or 1/2". It is critical to avoid seed placement at depths greater than this, however. Shallower seeding (on the soil surface) of prairie species is preferable to deeper. Although the results in this study were not conclusive, based on these results and the literature, it is the authors' view that late fall sowing (October/November) is a good time for prairie wildflower seed sowing, bearing in mind that there is great variability with respect to particular species success.

All of the experimentation in this study was directed at individual species. However, the authors believe it is critical to long-term success with prairie wildflowers that they be planted in diverse species mixes. These mixes should probably contain a component of prairie grass species too. Mixes should be composed of species that bloom at different times over the course of the growing season. Much further investigation is needed to refine recommendations concerning mixes.

7.3.1. Future Research Needs: Direct Seeding - Prairie Species

A large number of areas exist for further study to refine the use of prairie wildflowers on Indiana highways. Some of the areas of concern are:

1. Forb species mixes and grass/forb mixes - combinations and ratios of species.
2. Deep soil preparation - on compacted sites would subsoil plowing improve performance?
3. Weed control methods during establishment, especially cover or nurse crops.
4. Long-term establishment of slow to germinate species.
5. Long-term management to optimize wildflower longevity - mow, burn, herbicides, etc.?
6. If burn management is desirable, development of safe methods to employ burning on rights-of-way.
7. Improving the speed of seed germination (as a means to overcome weed competition and the problem of erosion on sloping sites) - is it technologically feasible using seed pre-treatment methods?

7.4. Recommendations: Transplant Establishment Methods

Transplanting of prairie seedlings offers an excellent alternative to direct seeding in limited areas and for purposes of establishment of more difficult to grow species. Based on the experimentation in this study, the following methods should be employed:

1. The optimum approach for prairie plant community establishment using seedlings would be to first establish, by direct seeding, a stand of native grasses. This should be done 2 to 3 years ahead of the forb transplanting. Then forb seedling should be installed.
2. Transplanting of prairie seedlings should be done during the warm soil part of the growing season, as long as adequate moisture can be provided through natural rainfall, or if that is lacking, with occasional supplemental irrigation.
3. Much remains to be learned about optimum containers for prairie transplants, but it should be recommended that relatively deep containers should be employed. The bigger the better. The Stewe system seems to work well, but several other container growing systems may work equally well. Conventional bedding plant cell-pack type of seedling containers are inadequate for the deep rooted prairie species and should be avoided.
4. The use of gel polymers or VAM fungi does not appear to be generally warranted as a means to improve plant establishment success.

7.4.1. Future Research Needs: Transplant Establishment Methods

Study is warranted into optimizing a container production system for prairie transplants. It should be studied in the context of mechanization of transplanting to facilitate future adoption on a large scale.

7.5. Recommendations: Costs

It is very important that care be taken in the interpretation of the cost projections. Recommendations based on the analysis, replete as it is with assumptions, is risky at best. Its purpose was to give INDOT a starting point for further evaluation of comparative costs of the use of wildflowers and other vegetation management options.

With the long-term cost savings inherent in the assumed reduced maintenance for all wildflowers, it should be our recommendation that all new landscape planting through the entire INDOT highway system be wildflowers. However, many questions still must be answered concerning the acceptability and feasibility of the assumed low long-term maintenance of wildflower plantings. Also, many other issues involving engineering, and biological, sociological issues, etc. have a bearing on vegetation management decisions. Cost, while very important, is not the only factor.

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