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16. Abstract
The purpose of this project was to investigate whether the Texas Department of Transportation's (TxDOT's) standard seed mix needs modifications to better address the issue of invasive species while the primary goal of erosion control can still be well achieved. The research objectives were to investigate: (1) the successional process of roadside grasses using TxDOT's seed mix and seeding procedure on field laboratory test plots and actual roadsides, (2) erosion control properties of vegetation on 12 new plots seeded with TxDOT's standard seed mix and 10 existing plots originally seeded with a non-TxDOT seed mix, and (3) the impacts of mowing on establishing and established grass communities. To achieve these objectives, the researchers conducted field laboratory experiments and actual highway roadside surveys. The results indicate that roadsides as maintained and mowed environments cannot be easily adapted by tall grass species (native or introduced). Short, sod-forming grasses, however, could grow better on roadsides. It was found that grass species in TxDOT's standard seed mixes did not show invasiveness on investigated laboratory plots and actual roadsides. The researchers also found little connection between original seeded grass species and observed grass species several years after seeding. This implies that volunteer species either from adjacent lands or from seed banks in the soil tend to dominate roadsides in the long term. All field laboratory plots controlled erosion very well. Yielded sediments were much below the TxDOT's minimum performance standards. Little literature was found on cost and benefit analysis about roadside management as a result of a lack of consistent cost database data held by state DOTs, which suggests future research on creating a database for comparing cost-benefit between the uses of natives and introduced grasses.

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SUCCESSIONAL ESTABLISHMENT, MOWING RESPONSE, AND EROSION CONTROL CHARACTERISTICS OF ROADSIDE VEGETATION IN TEXAS

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Dr. Ming-Han Li, P.E. (No. 91045).

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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INTRODUCTION

BACKGROUND

Texas and many other transportation agencies are under increasing scrutiny and pressure to utilize native plant seed on the roadside and to remove introduced species from seed mixes. Some of the most recent pressure is the result of Executive Order 13112 of February 3, 1999, on Invasive Species (Federal Register, 1999). This executive order was intended to prevent the introduction of invasive species and provide for their control, as well as to minimize the economic, ecological, and human health impacts that invasive species cause. This order presents a challenge for the Texas Department of Transportation (TxDOT) and other state departments of transportation (DOTs), as highway roadsides are not only built with imported backfill materials but these backfill materials are also applied using unnatural soil compaction techniques. With post-construction maintenance activities such as mowing and herbicide applications, roadsides are no longer virgin lands and these activities may exacerbate the effort to establish native grasses (Forman et al., 2003).

The purpose of this project was to investigate whether TxDOT's standard seed mix needs modifications to better address the issue of invasive species while the primary goal of erosion control can still be well achieved. The research objectives were to investigate:

- the successional process of maintaining roadside grasses using TxDOT's seed mix and seeding procedure on field laboratory test plots and actual roadsides,
- erosion control properties of vegetation on 12 new plots seeded with TxDOT's standard seed mix and 10 existing plots originally seeded with a non-TxDOT seed mix, and
- the impacts of mowing on establishing and established grass communities.

One project task was to extend the work conducted in Project 0-1504-2, Erosion Control and Engineering Properties of Native Vegetation Compared to Bermudagrass (Landphair et al., 2001), which compared the performance of native grasses, wildflowers, and forbs to Bermudagrass and Crown Vetch, which are both considered introduced species. The experiments were conducted on field laboratory plots at the Hydraulics, Sedimentation, and Erosion Control Laboratory (HSECL) of the Texas Transportation Institute (TTI). The original objective was to compare native plant communities to introduced species on the roadside. The 3-year project provided inconclusive results for a variety of reasons. In large measure, results were vague due to severe drought and very high temperatures experienced over the project duration.

When the 0-1504-2 project concluded, the test plots were left intact because there was no new work scheduled for that part of the laboratory. Since the project was completed, the plots continued to evolve and all 10 plots were almost completely covered with native and adapted species. Researchers used these plots in this project to document successional changes of grasses in a simulated roadside environment.

ORGANIZATION OF REPORT

Three materials are included in this final report:

- a written report,
- a training video in a DVD-ROM format, and
- visual documentation of highway roadside surveys observed in this project in a CD-ROM format.

The written report includes an extensive literature review with an outline of historic uses of native vegetation and roadside vegetation management issues, research methodology, results, and conclusions and recommendations. The DVD-ROM highlights the entire research project and was produced for training, demonstration, and education purposes. The CD-ROM includes visual records such as photographs and highway maps collected from the highway roadside surveys.

In summary, the outcomes of this project not only provide scientific evidence to support TxDOT's mission on roadside vegetation management but also create training and educational videos and brochures to enhance TxDOT personnel's understanding of TxDOT's mission on roadside vegetation management.

LITERATURE REVIEW

This project relies on both the research tasks at hand as well as on the previous and ongoing efforts of other researchers and their published studies. Reference to these other works serves to better inform both the methodology and the interpretation of results within this project. A review of these pertinent studies and their related literatures follows.

INTRODUCTION TO THE LITERATURE REVIEW

Research Project 0-4949, Successional Establishment, Mowing Response and Erosion Control Characteristics of Roadside Vegetation focuses on several issues dealing with roadside vegetation. Before examining and attempting to explain the natural process of succession in plant populations, several questions need to be addressed, first and foremost, "what is the roadside?" and "what is native?"

Once a suitable set of parameters for these two questions is formed to be used within the context of this project, some of the scientific questions can be explored within the literature. These include:

- Can a predictable climax community be achieved with a set planting mix, factoring in natural plant selection?
- How does maintenance affect the success and succession of native plant communities in a roadside environment?
- Can TxDOT assimilate native plant mixes into its roadside maintenance practices while still adhering to safety goals?

TxDOT already has made strides toward the broad inclusion of native species in roadside plantings. The TxDOT Landscape Specification Data recommends that:

> "proper plant materials is very critical. Because of the harsh conditions of the right-of-way, native and naturalized plants should be utilized when at all possible. These plants have adapted to withstand the extreme Texas temperatures, varying amounts of rainfall and differing soil conditions. And more importantly, these plantings require less maintenance, water and fertilization" (http://www.dot.state.tx.us/DES/landscape/planting/specifications.htm).

Incorporating more native species into the standard planting mixes parallels the emphasis on "proper" plant materials. Increasing the quantity of native seeds within the mix ratios is being studied for several reasons. Pressure to reduce upfront and sustained maintenance costs, concerns about plants' status on invasive species lists, and political realities bring to the fore discussions of best management practices.

Given the disparity of the current proven effectiveness of traditional seeding methods, yet the lack of substantive data regarding the success of fully native seeding methods, TxDOT launched a project to investigate full native plant seeding of roadside areas. Increasing seed ratios of native plants could prove to be less expensive over the lifetime of a project, increase public awareness, and maintain the coverage required in revegetation standards.

This literature review utilized a variety of sources and data sets and covered different disciplines dealing with native seed related issues for identifying methods that have potential application to TxDOT practices. Resources included university libraries across the country, government documents, academic journals/periodicals, trade magazines, and on-line resources. Studied fields covered ecology, horticulture, bioengineering, biology, and social sciences so that a better understanding of creating a successful native planting program could be achieved. Despite such a broad search, the literature review primarily focused on issues regarding establishment of natives and issues surrounding these practices. Additional advantages, such as wildlife habitat provision and aesthetic enhancement, are beyond the scope of the literature review and will not be discussed.

The successional processes of plant species within the environment, including roadsides, are inherently complicated. In nature, every species of vegetation competes for light, water, and nutrients appropriate to its needs. Plant species have developed physical and behavioral characteristics that optimize their ability to compete for resources of the natural environment. This process of competition can take hundreds of years or more under natural conditions, though there is little reliable research that provides proof. In general, a long-term survival process is a requirement of a 'native species' where a native species is one that occurs naturally in a particular region, ecosystem and/or habitat without direct or indirect human actions.

Experts support that native species have optimal characteristics to respond to their environment (Cole and Hundy, 1999). Despite the optimal characteristics of native species, their habitats are, in many areas, shrinking over time. This loss of natives is a result of changes in their environment, making them less dominant as species. They are no longer the best-adapted species after the environmental changes. It is widely known that human intervention is a major reason for recent environmental changes:

- unusual changes in the weather caused by deforestation,
- increasing use of chemicals,
- nutrition changes caused by fertilizers, water, and soil pollutants, and
- increases of non-native invasive species use.

Such changes within the environment are too diverse on a site-by-site basis to approach with any kind of general application.

Various surveys have observed the distribution of native and non-native species on roadsides. These results, even when focused on a limited area and utilizing different classifications of natives, well illustrate the pervasiveness of non-native plantings in roadside environments. Nearly 50 percent of plant species in study areas were non-native in New Zealand (Ullman et al., 1995) and Europe (Ullman and Heindl, 1989), although in South Africa only 26 percent were introduced species (Cilliers and Bredenkamp, 2000).

In addition, the current status of roadside vegetation knowledge appears to be still in the stage of exploration. For example, numerous studies about native vegetation establishment on the roadside suggest different or even conflicting findings. European researchers concluded that mowing could help increase establishment of natives (Melman et al., 1983; Persson, 1995; Ryel et al., 1996), while American studies recommended limited mowing (Ritzer, 1990; Bolin et al., 1990).

This discrepancy recalls Luken's (1994) argument that directions of scientific and ecological concern closely reflect social attitudes, in addition to the physical difference and preferred environment for survival of the natives in Europe and America. What still remains is the confusion or debate driven by politics, usually the environmental movement, and science. As a result, roadside vegetation management remains challenging for DOTs across the nation.

For appropriate use of such experimental knowledge, one must comprehend vegetation in general and successional processes, as well as understand site- or species-specific characteristics. Furthermore, as the U.S. government encourages the use of native plant species, current debates about the definition of natives or the justification of non-native use will deserve exploration. These issues will be paramount in this roadside plant study since they directly affect the regime of roadside vegetation management used by TxDOT and other DOTs.

What Is the Nature of the Roadside?

The roadside is defined as the area directly adjacent to the roadway. This narrow strip of land can be very diverse depending on the type of road, the width and slope of the right-of-way, and adjacent land uses. Both native and introduced (non-native) species are typically present in this narrow strip of the environment. Ullmann et al. (1995) writes "Areas suitable for arable farming or improved pasture support roadsides are dominated by introduced species, whereas less modified pastures or roads within native forests are associated with roadsides with a large component of native species" (Ullmann et al., 1995, pp. 441).

The nature of the roadside is controlled by several primary factors that can be identified as the major determinants of the character of a roadside environment. These include:

- the amount and frequency of maintenance,
- the roadway type and traffic frequency,
- the longitudinal slope of the roadway,
- the cross sectional slope of the right-of-way that includes the roadside area,
- adjacent land use characteristics (land cover, slopes, maintenance, etc.),
- stormwater management methods and structures,
- mowing height,
- soil compaction,
- existing plant mix, and
- exposure to roadway-based pollutants.

While no one factor determines the overall characteristics of the roadside, the roadway type typically plays a larger role than other factors. For example, roadsides along interstate highways are typically wider and largely unbroken, as design parameters for these roadways dictate buffer and safety zones that restrict access and accommodate high speeds. Alternatively, rural farm to market roadways typically include narrow rights-of-way, access points, and stormwater management structures that also serve surrounding land uses. Each of these roadside environments has dramatically different characteristics based on differences in the factors listed above that respond to the roadway type.

It is important to note that whether or not a roadside environment appears to be a "naturalistic" area, it is not an undisturbed natural environment regardless of the physical appearance. Soil conditions and the soil structure are typically highly modified to meet strict engineering properties. The hydrology of the roadside has also been completely altered from its pre-development condition and is designed to meet the requirements of the vehicular roadway. Finally, the roadside environment is also one altered by a continuous or at least a periodic source of automotive-based pollutants that could change the vegetation composition.

Deciding on a Definition of Native

Deciding on the definition of just what constitutes a native species is often the most problematic and politically debated issue discovered within the literature. Species, whether native or introduced, move across space in response to environmental changes. Kendle and Rose's (2000) definitions of native aim to filter between shifts caused by human actions and those that are not, but they have the tendency to fossilize plant and animal status as static and not adaptive (Brown, 1997). Perhaps one of the greatest problems with the concept of nativeness is that it commits one to supporting a flora that reflected a particular environmental and climatic state that cannot continue forever and has probably already changed (Kendle and Rose, 2000). While historically, a particular species could be found within the region, that region did not include the built roadway and its associated disturbances. From this perspective one can question whether or not a historically present species would be able to thrive given this new set of environmental characteristics.

Another definition of native is from the Nature Conservancy, through the Native Plant Conservation Initiative, that created the definition: A native plant species is one "that occurs naturally in a particular region, state, ecosystem, and habitat without direct or indirect human actions" (Morse et al., 2000). Most native plants have been in the same area for centuries or longer. However, the natural spread and dispersal of species (without human intervention) continues to occur, occasionally leading to an expansion of a species' natural geographical range (Morse et al., 2000).

The distinction between native and non-native species is important because native species have generally adapted and evolved with the competing species, predators, and diseases of an area over many thousands of years (Morse et al., 2000). Given the adaptations and resiliency that native species have acquired over time, defining what plants are native becomes an integral component in choosing site-appropriate plants for revegetation projects. Justification of a species specification involves supportive research that acknowledges choices will be successful once installed.

Notable Current Practices in Using Natives

Henderson (2000) notes that the increased awareness and desire to plant more natives has resulted in a dual system of management philosophies within "almost every DOT in the country." His observation is in respect to two competing points of view that cite financial and aesthetic interests to promote either more vegetation control or less vegetation control. DOTs try to satisfy both objectives and to meet some common ground between these viewpoints. As a result, roadside management programs are becoming much more integrated, with mixtures of controlled and uncontrolled areas.

One of the most complete programs of native plant use for weed and erosion control is Iowa's Integrated Roadside Vegetation Management (IRVM) program made law by the state legislature in 1998. Again, Henderson (2000) states that this legislation replaced pesticide control of weeds and revegetating with native species in roadside plantings because prairie grasses and wildflowers are the plants best adapted to local conditions and were most able to hold their own against weeds. Within the Iowa DOT IRVM Plan, weeds are not defined but are referred to as plants that are "undesirable" and "noxious."

The Federal Highway Administration's (FHWA's) definition of a weed is a "common term for invasive plants controlled over time by agricultural practices" (FHWA-EP-03-005, 2003). This term seems appropriate considering the adoption of the concepts of IRVM by the FHWA and the fact that the concept was created in the 1980s by Bill Haywood in Black Hawk County, Iowa (FHWA-EP-03-005, 2003).

This legislation allowed for the creation of a set of standards to be adapted to the needs of each district, with the primary focus being a "common sense interpretation" (Iowa DOT IRVM Plan).

Establishing Native Vegetation Cover on the Roadside

In an attempt to establish native vegetation on roadsides there are typically four options as described by Dawson and van der Breggen (1991). Their study lists the four options as: "no treatment, establishment of a purely indigenous cover, establishment of a combination of exotic and native species, and establishment of a temporary exotic cover" (Dawson and van der Breggen, 1991). In further detail, these options are as follows:

- "<u>No treatment</u> relies entirely on natural colonization by the local indigenous species. The site remains unprotected while colonization takes place. During this time the site is susceptible to weed invasion."
- "<u>Establishment of a purely indigenous cover</u> should be supplemented by natural colonization and is usually limited by seed availability, but avoids the problems of exposure and competition."
- "<u>Establishment of a combination of exotic and native species</u> results in competition, but with quicker cover establishment than when natural colonization is

relied upon, while the site is protected to a greater extent against erosion and weed invasion."

- "Establishment of a temporary exotic cover also relies on natural colonization. The indigenous vegetation has to colonize and establish in competition with the exotic species."

Topsoil Reuse for Native Revegetation

Native revegetation is often a problematic process riddled with issues including but not limited to seed collection, rate of emergence, and the viability of seed. One method to increase the effectiveness of native revegetation is to reuse native topsoil. To achieve this, topsoil removed in the construction process is held during the process and then reapplied to the same site in order to establish the preexisting vegetation cover from the existing soil seed bank. Skarindo et al. found that "The thickness of the excavated topsoil influences the availability of propagules" (Skarindo et al., 2004, p. 35). One potential issue of this process is the length of time that a soil stockpile is stored. "When comparing seed bank studies and revegetation from stockpiled topsoil (including the propagule bank, the micro fauna, flora and the nutrition), the effects of stockpiling on the soil quality have to be taken into account" (Skarindo et al., 2004, p. 35). This process is a potential method that can greatly aid in the reestablishment of native vegetation.

Addressing Revegetation Issues Using Native Plants

There is extensive literature about the use of native plants for revegetation. Much of the discussion and research focuses on restoration and reclamation issues. There is, however, little information regarding the use of native plants for roadside stabilization. The most specific information regarding the use of natives was found in trade journals. Kasperson (2004) reports that when individuals or agencies use revegetation as a means of erosion control, they will most likely encounter many different views on the use of native plants. These range from federal guidelines directing the planting of only native species on federal land to state, county, and local rules that vary widely on species mixes, cover ratios, and establishment time requirements.

Many erosion control projects involve immediate and specific concerns – revegetating quickly in construction areas for meeting the Clean Water Act, for example, where the first priority is protecting roads and development from runoff over barren earth during the next rainstorm. On roadside projects, what to plant may be determined more by questions of visibility (tall grasses interfere with drivers' line of sight) and ease of maintenance (how often do we need to mow it?) than by consideration of what once grew in the region.

Understanding current revegetation practices and their history are keys to developing new techniques for using natives more completely and addressing issues that arise when manipulating seed specifications that remove introduced species from a species list. Other issues to keep in mind with revegetation are the viability of native seed and the accessibility of quantities sufficient for DOT-scaled projects. Also seed germination practices, such as the use of nurse grasses, and the percent emergence of the seed are important factors in revegetation efforts.

Placing a Greater Value on the Use of Native Plants

Recent importance placed on the use of native plants partially stems from Executive Order 13112 of February 3, 1999. This regulation requires the use of native species to slow the use of invasive ones. For example, Texas invasive species inlucde Kudzu, Chinese Tallow, Saltcedar and Giant Cane. Portions of this Executive Order are as follows:

> **Sec. 2.**
> (2) Subject to the availability of appropriations, and within administration budgetary limits, relevant programs and authorities to:
>
> (iv) Provide for restoration of native species and habitat conditions in ecosystems that have been invaded;
>
> **Sec. 4.**
> Duties of the Invasive Species Council. The Invasive Species Council shall provide national leadership regarding invasive species, and shall:
>
> (d) Develop, in consultation with the Council on Environmental Quality, guidance to federal agencies pursuant to the National Environmental Policy Act on prevention and control of invasive species, including the procurement, use, and maintenance of native species as they affect invasive species; (6186 Federal Register, 1999).

Executive Order 13112 requires the National Invasive Species Council to produce a National Management Plan for invasive species every 2 years. A key element to the smooth functioning of this plan is the acknowledgement that each area is "unique" and that projects need to be based both on general principles and site-specific considerations and analysis. This plan responds to local conditions and in turn creates multiple management strategies in order to successfully respond to specific needs (National Invasive Species Management Plan, 2001, p. 80).

Specifying Native Seed

Specifying native seed is relatively simple and applicable for small projects. Project specifications of native seed often need to involve multiple levels of definition in order to provide the most appropriate site-specific seed mix for planting. Examples of these levels of definition that go beyond simply stating the species name include the following:

- specification of a particular ecotype seed, one that is specific to a particular site and its characteristics;
- specification that native seed be propagated from wild harvested seed stock instead of seed grown in monocultures within commercial farm operations; and
- specification of individual cultivars that have been improved by selective breeding.

As ecotypes are often best adapted to the local environmental conditions when non-local seed sources are used for a project, the plants may not be well adapted. This can not only lead to failure of the plants to persist (Handel et al., 1994) but can also result in genetic contamination of existing local populations of the species (Millar and Libby, 1989; Libby and Rodrigues, 1992; Knapp and Rice, 1994; Knapp and Dyer, 1997). This genetic contamination, however, may not be a negative aspect and may not result in anything more than a genetic crossover.

Propagated seed and cultivars are the most common, readily available, and typically adapted for larger growing areas. Propagation does produce large numbers of seeds without depleting the natural seed bank, but it also produces genetically identical clones, not genetically diverse individuals (Barnes and Washburn, 2000).

Barnes and Washburn (2000) report that seed suppliers need as much lead time as possible so they can plan their propagation and harvesting schedule in order to meet specific requirements. As an example of this, Wind River Seed in Manderson, Wyoming, a supplier of native seed for the Great Plains and intermountain regions, states that if a design specifies a very specific species, a contract for seed might have to be created up to 3 years in advance only if harvesting equipment is available. Since seeding and collecting windows for most native species are quite restricted, seed suppliers often must know at least a year in advance (Barnes and Washburn, 2000).

Issues Affecting the Establishment of Natives

The local environment affects plants where they grow; in turn, successional changes involved in the establishment of native vegetation can then change the very environment in which the plants grow. Issues affecting the establishment of natives can be summarized in three categories: competition, specific site issues, and suitability.

Competition

Existing species left on the roadside that were not removed by the construction process as well as vegetation on lands adjacent to the roadside project can create competition for the establishment of native vegetation. By their very linear nature, roadside environments lend themselves to being exposed to non-native species introduced by vehicles and others.

Vegetation that is not disturbed or removed during the construction process is typically already established and, in the case of many adjacent land uses, the existing species are maintained on a routine basis. Maintenance practices by adjacent landowners are usually directed to maintain the existing vegetation populations such as Bermudagrass lawns or rangeland grasses or crop grasses for agricultural purposes. These species, due their established nature and ongoing mowing maintenance that promotes their vigorous growth, pose great competition threats to the establishment of new native plantings.

The existing site seed bank is also a factor in establishment of natives on the roadside. The vegetation existing on site before the construction work is completed continually builds a seed bank in the soil. This seed in the soil can and will germinate after the construction process is complete, and many of the plant populations present prior to construction will reestablish the populations that the seed represents. This seed bank may or may not be similar to the native seed being planted. The strength of the seed bank after the disturbance to the soil will be an unpredictable competition factor and must be taken into consideration when planting for a native plant population.

Maintenance practices (mowing frequency and mowing height) applied to the roadside environment will also be a major factor in the competitiveness of certain grass species. It is well documented that certain grasses tolerate any frequency of mowing, whereas others are not as tolerant of even periodic mowing events. The grasses that are more tolerant of mowing will be able to out-compete the species that are less tolerant in maintained environments. This competition will result in a vegetative population that may be non-native. The resulting environment will be considered an altered environment by way of human disturbances.

Specific Site Issues

Choosing native seed for revegetation must address specific site conditions. Snider (1996) states that plans for stabilizing critical areas should tailor plant species to meet specific site conditions or problems.

> "...plant materials selected must be climatically and site adapted, require little maintenance, and be tolerant of drought, infertile soils, and other hostile conditions. Planting diverse mixtures of compatible grasses, legumes, forbs, trees or shrubs rather than the establishment of a single species simulates stable, natural conditions and improves the chances of successful restoration of the site" (Snider, 1996, pp. 1-5).

Barnes and Washburn (2000) note that natives are often the best choice in prevention of erosion when the application is for prairie establishment. There are general misunderstandings that native grasses are not well suited for erosion control because they are bunch grasses. In the book, *Prairie Plants and Their Environment: A Fifty-Year Study in the Midwest,* J.E. Weaver states:

> "Frequently, half – and often much more – of every plant...is invisible…. (For roots) of *Andropogon scoparius* ...a lateral spread of 1.5 feet in the surface foot of soil is usual and a depth of 5 feet is ordinarily obtained. The upper 2 to 3 feet of soil is especially well occupied, but branching is profuse almost to the root tips."

These grasses have tremendous root systems that hold the soil in place. The key for erosion control is applying sufficient seeds suitable for the environmental conditions. The benefits of using natives can be practical, ecological, and aesthetic. Native plants, once established, allow a healthy and functioning ecosystem to develop because they are adapted to the soil, temperature, and precipitation regime of their environment. Stable and diverse native plant communities provide such benefits as soil stability, water retention, and microclimate sheltering. Natives given sufficient growth mediums genetically adapt to local ecology, survive in diverse communities, and support local flora/fauna ecology. This gives ultimate stability in the long run when seeking erosion control, low maintenance, and restoration of sites (Barnes and Washburn, 2000).

Initiating plans for native seed introduction must begin with a thorough soil analysis. In many locations, human activity has so altered the soils and soil structures that survival of native vegetation might be unlikely and prohibitively expensive (Goff, 1999). As a result, the erosion control benefit from the natives may only apply to unaltered environments and not the roadsides unless specific measures are taken to build up suitable soils for native growth.

Suitability

Studies of the suitability of native seed mixes used on specific projects are important in order to build the case for the successful use of natives in roadside environments. The literature in this area, however, is lacking. Issues associated with site suitability for native grasses include:

- Where was the seed gathered?
- How do environmental differences between parent plant and progeny affect plant success?
- What is the genetic makeup of the seed being used?
- Will seed gathered in other regions of the state and even nationwide be able to adapt and thrive in a new environment?

Depending upon each specific site context and the desired outcome for the roadside site, these questions will need to be addressed. These questions point to the issue that it is unlikely that one seed mix of native grasses and flowers will suffice for an entire region or state. At the very least, each DOT will need to have at its disposal a set of several to many seed mixes that are appropriate to the various ecoregions of their state.

Recognition of the Difficulties and Varying Standards of Maintenance

In order for native plants to succeed, a specific maintenance regime must be followed. In order to outperform non-native species, Goff (1999) states that it is recommended to mow or burn according to a maintenance schedule that encourages the slower-growing natives to get a foothold. True weed abatement could take a year or two to complete (Goff, 1999).

Some maintenance regimes may be altered and even performed less frequently because of the strengths of native plants. The use of native species also has other advantages: regional adaptation can equate to a lower resource requirements such as water and nutrients, (Windhager, 2002) and natives can often be established with no fertilization on a variety of sites, including locations with poor soil characteristics and nutrition (Barnes and Washburn, 2000).

To control competition while native plants become established, mowing and herbicides may be used to effectively control weed growth. According to Chenoweth (2005), mowing can be used initially to help cut off weed seed heads and keep the canopy of the weeds down so new growth of native grasses will not be shaded out. After natives have established and if mowing is necessary, mowing is typically specified at a 6~7 inches or greater height. Shorter mowing can impact the reproductive parts of native grasses, especially warm-season grasses. Also, shorter mowing can cause sunscald and dieback of native grasses during the hot summer months. Broadscale applications of herbicides are often specified after native grasses have achieved deep root systems and reached mowing height, which is felt to be the stage during which damage from herbicides will not occur.

Using herbicides during establishment involves more skill. Newer herbicides that are less toxic and leave less residual are preferred. Hobbs and Humphries (1995) add that judicious herbicide use can now eliminate undesirable plant species while rendering little effect on native or desirable plant species. Research into chemical control includes the development of more efficient and environmentally friendly herbicides, but it also requires study of target species to assess their susceptibility at various stages in their life cycle.

Effects of Mowing Roadside Vegetation

Roadside mowing is one of the disturbances mentioned previously that has a considerable effect on vegetation's successional process. Mowing changes resource allocation by way of changing the light regime, increasing carbon allocation to shoots, removing nutrients, and disturbing soils. However, it is hard to generalize about the consequences of mowing since the environmental characteristics are not uniform across the roadside. Temperature, the amount of precipitation, the rate of human disturbance, various species characteristics, tolerance, speed of growth, and the mowing regime (i.e., when, how often, at what height) are all considerations in studying the effects of mowing on roadside vegetation.

A frequent mowing regime can create an environment advantageous to a certain grass species which cannot tolerate shade but has a great tolerance for disturbance. This selective feature can result in either the enhancement of the existing dominant species or their suppression. This result can lead to a more diverse habitat and trigger the dominance of another species.

Effects of Mowing on Resource Allocation

Light

The amount of light striking the surface of roadside vegetation will vary with different mowing practices. If the clippings are left behind they act as a shade to the plants that begin to regrow after being cut. If the clippings are baled and removed, parts of the plants that were shaded by the height of neighboring vegetation will be exposed to more direct sunlight.

Soil Nutrients

Soil nutrients vary widely across the right-of-way. When these rights-of-way are mowed and the clippings are removed, a large portion of the nutrients the plants had collected from the soil are removed with the clippings. This practice over the long term slowly depletes the soil of much-needed nutrients.

> "large amounts (over 50%) of nutrition appear to be lost from the cuttings. The losses were positively related to initial nutrient concentrations during a 6-week period. Mass and nitrogen losses were best explained by the initial C:N ratio, phosphorus and potassium losses by the initial phosphorus concentration" (Schaffers et al., 1998).

Soil nutrition is also altered by the practice of mowing even when the clippings are left behind. Once the mower has passed, the clippings remain for some time, yet some are blown by the wind to other areas adjacent to the right-of-way. The clippings that remain eventually decompose and their nutrients return to the soil to be used by the remaining plants. Not all of these nutrients are available, as some are leached or removed from the roadside area by stormwater movement.

> “potassium losses were particularly large (up to 90%). It is concluded that potassium is mainly lost by leaching whereas the major nitrogen, phosphorus and mass losses are most likely caused by a rapid microbial decomposition of readily soluble substances” (Schaffers et al., 1998).

Persson (1995) studied mowing of roadsides in Sweden with a focus on hay or grass clippings removal.

> A more conservation oriented mowing regime on the 250,000 hectares of roadside vegetation in Sweden would lead to a general improvement in diversity and provide many grassland species with better opportunities to survive in the future… The present practice of cutting the vegetation and not removing it does not seem to reduce the species diversity, at least not in the short-term. However this practice may increase the abundance of certain tall and fast-growing grasses and herbs, e.g. *E. repens* or *A. sylverstris*. In the long term this would cause a decrease in species richness, and hence the biological diversity. The non-mowing treatments in the study resulted in a decrease in diversity and an increase in coarse, tall-growing species and cannot be recommended for managing the type of vegetation described in the thesis.
>
> Mowing and cut removal: reduce standing crop (the amount of above-ground biomass) to almost half as compared the un-mown plots in short-term; decrease the abundance of several dominant species and increase slow-growing species; stimulate species in the seed bank to germinate. (However, the soil seed bank did not seem to influence species composition and abundance in the vegetation very much).
>
> Cutting the vegetation (*Anthrisicus sylvestris*) without removing it increased the abundance of species, especially at the Lana-site. The generalized use of this cutting regime in combination with atmospheric nitrogen deposition can probably explain why this species has so successfully colonized roadsides and other similar habitats.
>
> Species diversity was favored by cutting, but the increase was only significant when cutting was followed by hay removal. The increase in diversity index was mainly manifested as an increase in evenness, i.e. cutting tended to suppress the dominance of certain abundant species while increasing the abundance of more rare ones. However, there was also an increase in species number over time in the cutting treatments, indicating that species immigration had occurred. The absence of cutting among some of the plots creates shade and microclimatic conditions that are more favorable for the seed germination.

Persson (1995) shows that mowing and clipping removal can have a selective effect on roadside vegetation. Overall, cutting helped increase species richness and clipping removal helped boost that increase.

Effects of Mowing on Soil Disturbance

Mechanical damage by the mowers themselves with a moderate mowing regime did not significantly alter vegetation. Some specific species have an advantage in that their growth rate is increased by root fragmentation. This fragmentation can be caused by mowing disturbance of the soil (Steinlein et al., 1996).

When roadside areas are left unmown, species diversity is reported not to be negatively affected (Parr and Way, 1988; Ryel et al., 1996), nor does the absence of mowing directly increase species richness (Ritzer, 1990; Bolin et al., 1990). Parr and Way (1988) list two reasons why their study did not show a direct link between species diversity and mowing practices.

> "It is less clear why the absence of cutting did not lead to a decline in species richness in whole plots, but there are three possible explanations. First, some losses of grasses and herb species were offset by gains in shrub species…Second, the roadside verges used for the experiment were prone to occasional disturbances, e.g. car traffic, dumping of waste, hedgerow management, which may have created sufficient spatial diversity to maintain small populations of most species in the uncut plots" (Parr and Way, 1988).

Considerations in Mowing for Native Species Establishment

The timing of the actual mowing during the growing season may affect any species' ability to thrive in its environment.

> "The timing of a cut may also have a direct effect on the abundance of some species by determining their success at flowering and regenerating from seed. Early flowering species and some annual plants may be susceptible to a cut in late spring, which prevents them from setting seed... However, most grassland species are perennials adapted to continual defoliation, which maintain themselves by means of vegetative reproduction and occasional seed germination. Variations in the timing of cuts usually have a more immediate effect on the structure of the vegetation than on its species composition" (Parr and Way, 1988).

The frequency at which a roadside is mowed can have implications on rates of establishment and species diversity. Cutting more often provides an advantage to species that grow fast and can rejuvenate quickly after being cut. Frequent cutting allows these faster species to compete with larger naturally dominant species.

> "Mowing frequency was a major factor affecting the species composition of the roadside verge grassland communities represented in this experiment... an increase in cutting frequency leads to a gradual change in species composition, with coarser species declining and low growing or prostrate species increasing. The net effect is usually for cutting to increase plant species-richness... Cutting probably enhanced diversity by reducing the size of individual plants and enabling more species to co-exist in a small area" (Parr and Way, 1988).

The cut height of roadside vegetation can also have an impact on species diversity and rates of establishment. As mentioned before, the rate of cutting can select species that are fast at regenerating plant tissue. The height of the cut also favors plants that can regenerate quickly. The height of the cut may also affect different plants differently. The cut may remove the flowering portion of a plant if it is in the flowering stage of growth. Removing the flowering portion of the plant can also cause a decrease in establishment rates and/or reduce species diversity if certain species are eliminated.

Clipping removal is another aspect of native species establishment. Marshal and Nowakowski, (1995) found that "cutting yearly in spring and late summer, with removal of cuttings, reduced the rate of species loss in a sown grass/wildflower field margin strip over a 5-year period and was recommended for maintaining plant species diversity" (Marshall and Nowakowski, 1995, p. 88). With respect to wildflowers specifically, Cauwer et al. found that mowing did not significantly alter the rate of wildflower reemergence over several years (Cauwer et al., 2005, p. 91). Cauwer also found that: "Three years after installation, species diversity was significantly higher under a mowing regime with complete removal of cuttings than under a regime with no or partial removal of the biomass" (Cauwer et al., 2005, p. 94). The reasons that removing clippings adversely affects establishment is in mineral depletion of the soil, which in turn promotes development of botanically diverse vegetation (Cauwer et al., 2005, p. 95).

Similar to clipping removal, grazing also shortens the plant and removes tissue. Several studies of grazing on pasture land have been conducted, but few focus on grazing the roadside. Of those studies of pasture grazing, Zhang states that: "Introduction of heavy grazing often initiates a retrogressive succession, including a decrease in biomass and in structural complexity" (Zhang, 1998, p. 1365). This process would have negative effects on the roadside where diversity is a key aspect of other processes conducted by roadside vegetation. Furthermore "The higher species richness and cover of annuals in the control suggest that grazing had a facilitating effect through the reduction of the perennial cover" (Zhang, 1998, p. 1375). This too would be a net negative effect on roadside vegetation. Perennial grasses are the key to holding the right-of-way against the power of erosion. This loss of perennial grasses would be disastrous to roadside vegetation establishment and success. Rusch and Palacios state that a loss of perennial species shows that annual species portions may be a result of fertilization through urine and feces deposition by large herbivores (Rusch and Fernandez-Palacios, 1995, p. 417).

Montalvo et al. claim that: "Grazing should not be considered as a disturbance in some ecosystems with a long history of herbivory" (Montalvo et al., 1993, p. 213), and yet Pykala states that "One of the main problems (of natural vegetation restoration) is the high nutrient levels in cultivated soils" (Pykala, 2003, p. 2212). It is clear that the two articles are speaking in different contexts but the contradiction is still compelling. One states that grazing is not a disturbance, and yet the other states that the related effects of grazing could be one of the many factors reducing the effectiveness of native species re-establishment.

Johansson and Hedin state that: "Among North European nature conservation managers, cattle grazing is considered more suitable for plant diversity than sheep or horse grazing" (Johansson and Hedin, 1991). Pykala explains: "This is mainly due to the fact that cattle graze less selectively than sheep and horses" (Pykala, 2000, p. 2221) and "Thus cattle grazing appears to be beneficial to plant species richness independently of the study scale" (Pykala, 2003, p. 2221).

In the end, grazing may not be a practical method of height control for the roadside, but it does lead to an interesting discussion of how adjacent land use vegetative control is related to native species establishment and control in the right-of-way. Zhang puts it well: "There is not one given direction of change in plant species diversity in relation to grazing or the cessation of grazing" (Zhang, 1998, p. 1379). His statement shows that more research and understanding is necessary to further the discussion on grazing.

Comparison of Erosion Control and Soil Engineering Properties

Landphair et al. (2001) studied erosion control and engineering properties between native vegetation and Bermudagrass. Specifically, this project observed the performance of native plant materials with an introduced species commonly used in erosion control mixes for the stabilization of roadsides. The research questions were:

- Do the native grasses, forbs, and wildflowers provide better or equal erosion protection to the roadside as measured by sediment reduction?
- Do the native species have the ability to maintain themselves and resist invasion of other species based on percent of surface cover?
- How do native species compare in terms of their soil nailing and reinforcing characteristics with respect to sliding based on surface shear strength?

The study found that the native species' success at erosion control on steep slopes was dependent on several factors, but in the end they were comparable but no better than existing TxDOT seed mixes (Landphair et al., 2001, p. 6).

On the whole, the assessment that native vegetation species are a potential tool in the vegetation management scheme of a transportation system is based on several considerations:

- roadside mowing practices and use of herbicides,
- public sense of aesthetics,
- safety considerations,
- potential invasion of woody species, and
- areas where the use of natives is more applicable and requires greater consideration.

However, when all properties are considered, natives are in no way superior to the vegetation mixes currently in use by TxDOT and other transportation agencies of the southwestern region of the United States.

Specifically, wildflower mixes did not perform well in erosion control and were not recommended. Other native mixes were conditioned on site environments and maintenance practices (Landphair et al., 2001).

Successional Process

Tinsley et al. (2005) reported that some native grass species may be more suitable for springtime roadside revegetation projects than TxDOT seed mixes. Tinsley et al. (2005) drew this conclusion because they found that the native seed mix developed more seedlings within 60 days. This conclusion seems plausible, yet such a conclusion, as they state, is very limited. The actual field environment is not as simple as the test environment (i.e., different seasons, different nutrition levels, and more competitor species). Moreover, the test time may also be a significant limitation; a 60-day period is not long enough to determine the dominance in competition among species. Species dominance can only be determined when the species survives for a much longer time. The diversification of reestablished grasslands can be divided into four phases:

- "transfer of propagules from existing vegetation (or seeding),
- germination and establishment of seedlings,
- survival to maturity, and
- periodic re-establishment."

Succession refers to this series of changes in thespecies composition of a community (Drury and Nisbet, 1973).

As each species has a different phenological cycle and tolerance to given environmental conditions, the competitive power of each species can continuously vary through time (i.e., height change adjusts opportunity for photosynthesis, deeper or wider root systems increase the ability to obtain nutrients and to propagate, weak tolerance to disturbance may reduce survival chances when mowing frequency increases). According to Hodgson (1998): "The succession of naturally revegetated strips is characterized by an initial dominance of annuals and short lived species, which are, with time, typically replaced by perennial non-woody species, and secondly, if no mowing regime is applied, by shrubs and trees" (Hodgson, 1998, p. 88). Cauwer and his team found that: "Initially, species diversity was significantly increased by sowing species-rich mixtures. However, in the subsequent years, floristic diversity of sown communities decreased (commercial community) or remained stable (native community)" (Cauwer et al., 2005, p. 94). Cauwer's research is not without its validity issues, as the group states: "Unfortunately many succession studies concerning margin strips do not contain unsown plots. It is therefore impossible to know how effective the addition of seed mixtures has been in accelerating or diverting succession or species composition" (Cauwer et al., 2005, p. 88). A good understanding about which factors affect vegetation growth will also be a good set of indicators to judge how to control successional processes.

Factors for the Successional Process

Simply put, the factors of vegetation growth can be divided into three parts:

- environmental resources including light, water, air, and nutrients;
- environmental changes or human disturbances; and
- vegetation characteristics reactive to such environmental factors.

Resources (Light, Water, Air, and Nutrients)

Photosynthesis requires light as well as other non-mineral nutrients including hydrogen, oxygen, and carbon. In addition, various mineral macronutrients are required for the growth of plants. Among these six macronutrients, plants heavily consume nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur; plants will compete with other species for all nutrients, but especially for nitrogen, phosphorus, and potassium. These three are especially essential for photosynthesis, rapid growth, and immunization. They are usually lacking in many soils and tend to be the limiting factors of plant growth (NCDACS, 2005).

The amount and intensity of light varies from site to site along roadsides and is greatly dependent on adjacent land uses. The natural growth habit and physical structure such as the height of a grass species determines its competitiveness for light. The amount of water available to a site greatly varies from region to region. The physical structure of a grass root system also has a great effect on its ability to compete for water, which is often a limiting factor in roadside growth. Each roadside has different level of automotive traffic. This difference in traffic and its resulting exhaust, which includes carbon, nitrogen, and phosphorus, as well as the other types of nutrients usually found in prepared fertilizers, can have a small effect on soil fertility. This difference in nutrient distribution may be one reason that explains the variety of successional processes in roadside vegetation habitats. It may also indicate the specific circumstance of patchiness of roadside vegetation.

Roadsides have additional nutrient sources and may even contain heavy metals which natural pastures/forests do not have. They include:

- vehicle emissions or nutrition from the atmosphere (Parr and Way, 1988; Schaffers et al., 1998);
- hay cut caused by mowing (Parr and Way, 1988; Persson, 1995);
- runoff or splash of de-icing salt from road surfaces (Parr and Way, 1988);
- nutrient-laden runoff from adjacent agricultural areas (Parr and Way, 1988; Cale and Hobbs, 1991); and
- debris from the destruction of roadside hedges (Parr and Way, 1988).

To infill with native species or to increase species diversity on roadsides, most studies of the effects of nutrition levels on successional processes recommend the strategy of reducing nutrient amounts. This strategy is drawn from the idea that roadside environments are generally oversupplied with nutrients and such nutritional surpluses benefit limited strong species (Cale and Hobbs, 1991; Ullmann et al., 1995). Many European studies recommend clipping removal after mowing on roadsides since clippings are a major source of nutrition (Melman et al., 1983; Persson, 1995; Ryel et al., 1996). This beneficial nutrition often leads to reductions in biodiversity on behalf of species that thrive in the nutrient-rich clipping environments.

Disturbance and Compaction

High rates of disturbances including mowing, herbicide applications, grazing, installing/repairing utilities, and road traffic are typical characteristics of roadside environments. It is widely accepted that disturbance facilitates invasion of non-natives (Crawley, 1987; Wiser el al., 1998).

One possible explanation of this is that disturbance affects resource flux as described by Rejmanek:

> "Environments subject to pronounced fluctuations in resource supply will be more susceptible to invasions than environments with more stable resource supply rates... environments will be more susceptible to invasion during the period immediately following an abrupt increase in the rate of supply or decline in the rate of uptake of limiting resources" (Rejmanek, 1989).

However, other researchers feel that disturbance is a negligible factor for the introduction of non-natives (Wiser et al., 1998). This contradiction may be due to the different level of susceptibility of each habitat; that is, habitats composed of populations vulnerable to disturbance are more susceptible to invasion and vice versa. In this sense, the invasion issue is directly related to population diversity. Disturbance may weaken predominant species, thus providing a greater opportunity for other species to survive. Stronger species, which could thwart the growth of weeds, might not allow other non-invasive species. Besides, the decline of currently dominant species does not necessarily lead to an increase of diversity but sometimes results in the development of a new predominant species. It has been suggested that limited mowing is a more effective way of reestablishing a diverse and native vegetative colony in the United States (Bolin et al., 1990; Ritzer, 1990). However, other studies demonstrate that the elimination of mowing develops stands of only one or two dominant plants (Schutt and Teal, 1994).

Roadsides are commonly compacted for structural purposes. Compaction is typically conducted in a way that significantly changes soil properties such as density and permability. Therefore, due to compaction, plant succession on roadsides is affected.

Inherent Characteristics of Vegetation Species

Inherent characteristics of plant species are a major factor of the successional process. Plant morphology such as root systems, plant height, leaf shape, leaf color, tolerance to disturbance, reproductive behaviors, etc., are directly related to their competitiveness and survival. The survival of native species in human environments seems to be directly dependent on their inherent characteristics. The ability of native species to establish in severely disturbed habitats often determines dominance along roadsides (Ullmann and Heindl, 1989).

Jain and Martins (1979) arrange the genetic and behavioral characteristics of roadside colonies where a greater amount of reproductive *effort* occurs in their statement that:

> "Roadside colonies showed a greater amount of reproductive effort. (1) In genetic structure, increased outcrossing rate, high genetic variability within population; (2) in dispersal pattern, local dispersal limited (concentrated in specific area), neighboring colonies interpollinated, moving of soil and grazing animals and traffic perhaps aid in long distance dispersal; (3) in germination and survivorship, lower rate of seed carryover (= higher germination rates), higher and more stable plant density, and lower seedling survivorship (= higher self-thinning); (4) in reproduction, earlier flowering in response to more aridity, larger plant size at maturity, and larger and more hairy calyx."

Several studies demonstrated the possibility of genetic evolution and adaptation to changing environments (Baker, 1974; Jain, 1976; Wu and Antonovics, 1976). Such development may not only increase species survival opportunities but also trigger weed infestations. Wu and Antonovics (1976), through a research project on the evolution of tolerances to high pH level on the roadside, found that high pH levels had no clear effects on species with a greater inherent tolerance but did affect sensitive species, which become indicators of environmental health. These findings demonstrate the natural evolutionary process of native species in reacting to environmental change. Ironically, it may also reveal that such evolution of a species results in the loss of the term "Native" and are better defined as one developed by unintentional selection. Human altered environments often require inferior natives to be genetically altered to survive.

Any change in each of the three factors: resources, disturbances, and species characteristics can change power relationships among plant species. Non-natural alterations of the environment can alter such factors, whether intended or not. Mowing and applying herbicides is an environmental altering activity that affects the natural selection process and in most cases is a necessary practice of the roadside.

Use of Non-Natives: Is it Positive or Negative?

This aspect could very well be the focal point of the entire study at hand. There are many aspects that go into a positive or negative rating, but these are too many in number to argue here. Some specific mentions of positive or negative attributes of non-natives are discussed below.

"The invasion of non-indigenous plants is considered a primary threat to integrity and function of ecosystems" (Blossey et al., 2001, p. 1787). Blossey goes on to mention in his paper that these negative impacts may not be fully realized but at the same time their possible threats are no less likely and that low numbers of non-indigenous plants may have no cumulative negative impacts at all.

On the other hand Yan et al. in their article say that: "China has a long history of introduction of non-native species, especially species proven to be productive elsewhere and offering potential economic benefits to China" (Yan, et al., 2001, p. 1317), thus leading one to believe that non-native plants may not deserve the negative stamp that has been branded on them.

One of the biggest threats that invasive species carry with them is the ability to destroy habitat by reducing species diversity. "Alien plant species are increasing in frequency and abundance in many natural areas in Spain, often favored by disturbance and habitat fragmentation" (Heywood and Iriondo, 2003, p. 321). Likewise in coastal regions "These ecosystems are one of the most threatened and affected by the invasion of alien plants, especially shore dunes, salt marshes and cliffs. These kinds of habitats, especially the dunes, experience significant pressure from human activities which favors the expansion of some of these species…" (Campos et al., 2004, p. 2275).

It seems that the debate will continue on either side of the non-native species issue, but the presence of non-native species in natural environments is a fact. These species will be here to stay, so the opportunity to find positive uses for them is ours.

Does Non-Native Mean Invasive?

Invasive is a hard term to define, as is alien or controlled species. These terms are hard to define because these terms include both temporal as well as geographic dimensions. Regarding the temporal, is it difficult to draw the line in time between original or native species and a label of invasive species? Samways (2000) argues that:

> "Bringing back the evolutionary potential to some extent, deals with the agonizing historical aspects of 'restoring' for when? Pre-alien invasions, pre-industrial, pre-European, pre-human? Restoration, at least when viewed biocentrically, is about re-permitting ecological integrity, natural successional processes and evolutionary opportunities" (Samways, 2000, p. 1077).

The geographic dimension is slightly easier to deal with but still poses a problem at the fringe of a geographic area. Climate zones and eco-regions are the existing standards in determining nativeness in geographic terms. Previously mentioned is the question whether there is any overlap when two eco-regions come together and, if not, where is the exact boundary?

Other factors dealing with invasive species are climatic and elevation changes over a specific site. Arevalo in his study found that: "Investigating the relationship between climatic matching and invasion success is also important for evaluating how invasive species might spread under climate change" (Arevalo et al., 2005. p. 186). There are even more factors influencing invasive species and these factors exert various pressures upon a species' invasiveness.

Invasive species are hard to define because of the various issues related to their definition. Once these issues are clearly separated from each other a non-native species has the potential to be defined as invasive or not.

Aesthetic Diversity or Function

Aesthetics or the perception of the human eye and the thoughts of the mind are the most ambiguous measures of science. Beauty lies in the eye of the beholder, or one person's art is another person's junk. "And as we cannot measure every aspect of composition, structure, linkages, and function, what we are doing is as much art as it is science" (Samways, 2000, p. 1078).

Is a 'natural' landscape art, and is the roadside the appropriate place for art? These are the true questions of aesthetics in this paper. As these questions are subject to blurry science at best, the debate must rest on other applications of native vs. introduced such as engineering capabilities, safety issues, and others. Although the science is blurry in respect to what is pleasing to the eye Statens has this to say about the overall aesthetic goal: "Preservation and re-establishing indigenous vegetation helps to reach the official goal: to restore degraded areas and to improve road aesthetics within the natural landscape" (Statens, 1992).

Between extremes of restoration (a biocentric, deep-ecology exercise) and regreening (an anthropocentric, aesthetic, a vegetation-only orientated, sometimes engineering exercise) are the realms of ecological landscaping (landscaping with an ecologically reasoned approach, but with aesthetics and human cultural considerations not a top priority) and rehabilitation (ecological recovery with major aesthetic and/or human cultural components and with an ecological component that suits the situation, e.g., grass that survives on the faces of goldmine dumps, rather than specific attention to recreating the 'original' ecological integrity) (Samways, 2000, p. 1079).

Understanding the Limits of Current Studies

Little research has been conducted on native plants and their role in erosion control. DOTs typically tend to avoid planting native grasses as short-term problem solvers and, as a result, may miss out on their long-term benefits. New York DOT selects native species for lower maintenance purposes but they "don't feel...native grasses are good candidates since they don't provide quick, dependable, and persistent erosion control" (Henderson, 2000, p. 15). Concerns about growth rates are typically mentioned as reasons not to plant natives without acknowledging that most literature reflects a multi-year time for natives to establish themselves fully.

Several studies have shown success in revegetation with native species. Studies of revegetation efforts on steep slopes in the western United States were done by Gerschefske et al. (1987) and Paschke et al. (2000). Both studies were directed within harsh environments and attempted to establish natives in highly saline soils on greatly disturbed sites. Both studies reported at least marginal (Gerschefske, Kitt, and Sabey) vegetation establishment to successful establishment (Paschke, Deleo, and Redente). Their ultimate goal of stabilization of steep slopes, with vegetation establishment, was successful. Plants used for this study were mostly shrubby perennials with some grasses. These plants were not subject to any type of mowing regime.

Parallels to our current project can be drawn to work done in California by Bugg et al. (1997) from 1992 to 1994. This work compared coverage to two mixes of native perennial grasses (8 species and 13 species) to that of a non-native perennial grass mix (3 species). This study was conducted on rural roadsides to evaluate reduction of the threat of flooding, erosion, siltation, wildfire, and the incidence of resident vegetation as well as coverage rates and quantities. Roadsides were categorized into topographic zones, initiating the idea of options for species variety based on location. Focusing on erosion control and weed suppression was a primary guide, and therefore canopy cover was equated to successful establishment (Bugg et al., 1997). Results from the study demonstrated progressive success for each year with demonstrable increased native coverage and reduced weed coverage.

METHODOLOGY

ROADSIDE FIELD SURVEY

Texas highway roadsides representing different geographical locations were selected for documentation of present vegetation. This task treated the roadsides as field laboratories, and a preliminary hypothesis testing on the successional change of roadside vegetation was conducted. The research team investigated a number of roadside sections to develop a general characterization of the roadside population composition.

Selection of Candidate Roadsides

To select appropriate roadsides for field survey, the researchers used the following criteria:

- roadsides were to be on rural highways,
- highway roadsides had a minimum of 5 years of vegetative growth after the completion of major highway construction or rehabilitation,
- availability of original roadway construction documents,
- availability of roadside soil type information,
- known seed mix makeup originally used for roadside slope stabilization, and
- mowing schedules available for the past 5 years.

TxDOT provided information for the researchers to identify appropriate candidate sites to survey. Using these criteria, the researchers visited seven Texas highways representing different geographical locations and ecoregions (see Table 1). Initial visits of five highways (FM 534, FM 3509, SH 29, RM 1431, and US 287) were to obtain preliminary impressions of vegetation growth conditions. Finally, two highways (FM 70 and SH 47) were surveyed in detail.

Table 1. Surveyed Highways.

District	Ecoregion	Survey Time	Surveyed Highway	Number of Lanes	Remarks
Corpus Christi	Western Gulf Coastal Plain	July 2005	FM 70	2 (undivided)	Detailed survey conducted
		July 2005	FM 534	2 (undivided)	
Austin	Texas Blackland Prairies	July 2005	FM3509	2 (undivided)	
		July 2005	SH 29	2 (undivided)	
		July 2005	RM 1431	2 (undivided)	
Wichita Falls	Central Great Plains	October 2005	US 287	4 (divided)	
Bryan	Texas Blackland Prairies	March 2006	SH47	4 (divided)	Detailed survey conducted

Data Collection

The goal of the data collection was to focus on grass species that were present in abundant quantities on the selected roadsides rather than an inventory of all species. An approximate 5-mile (8.5 km) segment was surveyed on FM 70 and SH 47 roadsides. Both segments are considered rural highways that have no curbs between the pavement and grassy roadsides. Surveyed stations were 0.5 mile (0.85 km) apart along the segment and covered 200 feet (61 m) of rights-of-way longitudinally on both sides of the roadway. The quantity and types of grass species were visually assessed and documented for different strips of each roadway section, including the front and back slopes (Figure 1). One particular reason that the front and back slopes were treated separately in data collection is that different roadside slopes typically have different mowing schedules. Front slopes are mowed three to four times per year, while back slopes are typically mowed two times per year. The quantity of noticeable, dominant grass species was estimated visually by its average cover at each of the survey stations. No transects or detailed inventories were conducted.

In addition to grass species, original soil data were also collected for analysis. The soil data for each survey station were obtained from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service's Web Soil Survey program website (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). The soil type data were retrieved from the website and described using the USDA Textual Classification terminology such as sandy loam, loamy sand, sand, and clay.

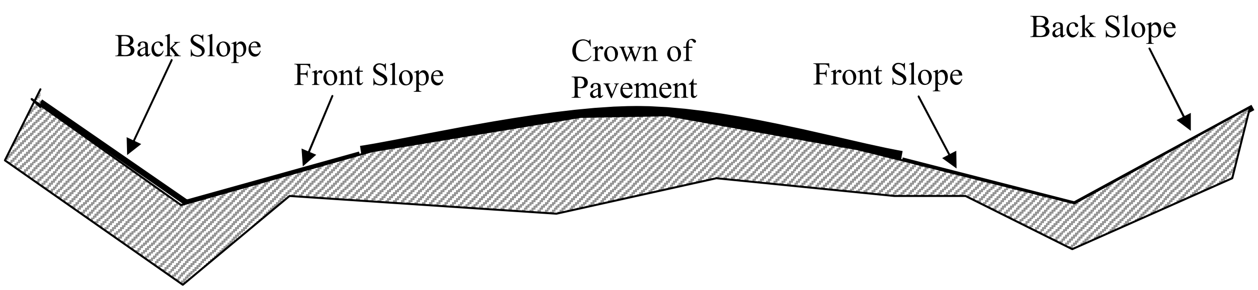


Figure 1. Typical Texas Rural Roadway Section.

Existing Field Plot Monitoring Experiment

In the existing field plot monitoring experiment, TTI researchers used 10 plots on full-scale embankments, seeded with various grasses and forbs dating back more than 5 years that were located at the Hydraulics, Sedimentation, and Erosion Control Laboratory. The 10 existing field plots were previously used for TxDOT Project 0-1504 "Erosion Control and Engineering Properties of Roadside Vegetation" completed in 2001 (Landphair et al., 2001). Five plots were on 33 percent slope of sand; the other five on a 50 percent slope of clay. Test plots were named to reflect their testing seed mixes. They are:

- control plot,
- native grasses plot,
- wildflower mix plot,
- native forbs and grasses plot, and
- crownvetch plot.

None of the existing plots were seeded with TxDOT standard roadside seeding mixes. Table 2 presents the original seed mixes on existing plots. Each seed mix was tested on sand (33 percent slope) and clay (50 percent slope) plots.

In the beginning of this research project (August 2005), these plots were completely covered with dense vegetation (see Figure 2). The vegetation inventory of these plots consisted of a systematic walk-through, identifying the species found and the relative abundance of each species. The inventory data represent the growth condition 6 years after the plots were seeded. The plot size was 66 feet (20.1 m) long and 20 feet (6.1 m) wide on 33 percent slopes and 50 feet (15.2 m) long and 20 feet (6.1 m) wide on 50 percent slopes. Because these plots had been left alone since seeding, their undisturbed vegetation succession could be assessed. In addition, the erosion control performance of these plots was tested using artificial rainfall simulators. Details of erosion control testing are described in section "Erosion Control Properties." Meanwhile, the inventory data were used as the initial condition for the test of mowing described in section "Mowing" and the test of erosion control properties described in section "Erosion Control Properties."

Table 2. Original Seed Mixes for Existing Plots.

Plot Name	Species		Seeding Rates (lb/acre)	Seeding Rates (kg/ha)
	Botanical Name	Common Name		
Control	*Cynodon dactylon*	Bermudagrass	16.57	18.57
Native Grasses	*Bouteloua curtipendula*	Sideoats grama	39.61	44.40
	Elymus canadensis	Canada Wildrye		
	Koeleria macrantha	June Grass		
	Panicum virgatum	Switchgrass		
	Schizachyrium scoparium	Little Bluestem		
	Sorghastrum nutans	Indiangrass		
	Sporobolus heterolepis	Prairie Drop Seed		

Table 2. Original Seed Mixes for Existing Plots-Continued.

Wildflower Mix	*Achillea millefolium* *Castilleja indivisa* *Centaurea cyanus* *Chrysanthemum leucanthemum* *Coreopsis lanceolata* *Coreopsis tinctoria* *Coreopsis tinctoria*, dwarf red *Cosmos sulphureus* *Delphinium ajacis* *Echinacea purpurea* *Eschscholzia californica* *Gaillardia pulchella* *Gypsophila muralis* *Linaria maroccana* *Linum rubrum* *Lupinus subcarnosus* *Monarda citriodora* *Nemopila insignis* *Oenothera speciosa* *Papaver rhoeas* *Phlox drummondii* *Ratibida columnaris* *Rudbeckia amplexicaulis* *Rudbeckia hirta* *Verbena rigida*	Yarrow Texas Paintbrush Cornflower Ox-eye Daisy Lanceleaf Tickseed Plains Coreopsis Dwarf Red Coreopsis Yellow Cosmos Rocket Larkspur Purple Coneflower California Poppy Indian Blanket Baby's Breath Toadflax Scarlet Flax Texas Bluebonnet Lemon Mint Baby Blue-eyes Showy Primrose Corn Poppy Drummond Phlox Mexican Hat Clasping Coneflower Black-eyed Susan Tuber Vervain	18.64	20.89
Native Forbs and Grasses	*Asclepias L.* *Bouteloua curtipendula* *Callirhoe involucrata* *Castilleja* spp. *Coreopsis tinctoria* *Elymus canadensis* *Gaillardia aristata* *Helianthus maximiliani* *Liatris mucronata* *Lupinus texensis* *Machaeranthera tanacetifolia* *Monarda* spp. *Oenothera hookeri* *Penstemon strictus* *Petalostemum purpureum* *Rudbeckia hirta* *Salvia farinacea* *Schizachyrium scoparium* *Sorghastrum nutans*	Milkweed Sideoats Grama Wine Cup Indian Paintbrush Plains Coreopsis Canada Wildrye Blanket Flower Maximilian Sunflower Gayfeather Texas Lupine Prairie Aster Bergamot Yellow Evening Primrose Rocky Mountain Penstemon Purple Prairie Clover Black-eyed Susan Mealy Blue Sage Little Bluestem Indiangrass	18.64	20.89
Crownvetch	*Securigera varia*	Crownvetch	18.64	20.89

Figure 2. Dense and Tall Grasses on Existing Plots (August 2005 Photo).

New Field Plot Monitoring Experiment

A primary objective of this project was to document the transitional development stages of roadside vegetation populations from the initial planting to the mature plant community that will evolve over time. Because none of the existing plots used TxDOT standard roadside seeding mixes, the successional change originating from TxDOT's seeded species cannot be studied on existing plots. In order to evaluate the ability of TxDOT seed mixes to foster a similar development of climax native grass communities on the roadside, a new set of field plots was installed. The same monitoring method as described in the section "Existing Field Plot Monitoring Experiment" was used. The vegetation inventory of these plots consisted of a systematic walk-through, identifying the species found and the relative abundance of each species.

Plot Preparation and Seeding

Twelve new plots, all on a 33 percent slope, 20 feet (6.1 m) wide by 66 feet (20.1 m) long, were constructed as a comparison group to the existing one. The construction process of new plots is illustrated in Figure 3. Six were on clay; and the other six on sand. The new plots were seeded in compliance with the specifications for TxDOT's Bryan District. Table 3 presents the seed mixes and their application rates for new plots. Seeds were applied by a hydroseeder and mixed with spray-on mulch. After installation, the new plots received no supplemental water or other maintenance except for necessary artificial rainfall testing and scheduled mowing. Artificial rainfalls were used for erosion control testing. Details of erosion control testing are described in section "Erosion Control Properties."

(a) Graded New Plots

(b) Seeded and Mulched New Plots

Figure 3. Construction and Installation of New Test Plots.

Table 3. Seed Mixes and Rates for New Plots.

Plot Type	Species		PLS Rate (lb/acre)*	PLS Rate (kg/ha)
	Botanical Name	Common Name		
Sand	*Cynodon dactylon*	Bermudagrass	1.5	1.68
	Eragrostis curvula	Weeping Lovegrass (Ermello)	0.6	0.67
	Eragrostis trichodes	Sand Lovegrass	0.6	0.67
	Leptochloa dubia	Green Sprangletop	0.3	0.34
	Paspalum notatum	Bahiagrass (Pensacola)	7.5	8.41
	Coreopsis lanceolata	Lance Leaf Coreopsis	1	0.34
Clay	*Bouleloua curtipendula*	Sideoats Grama (Haskell)	3.6	4.04
	Cynodon dactylon	Bermudagrass	1.5	1.68
	Desmanthus illinoensis	Illinois bundleflower	1	1.12
	Leptochloa dubia	Green Sprangletop	0.3	0.34
	Schizachyrium scoparium	Little Bluestem	1.7	1.91

* Pure live seed.

Erosion Control Properties

Roadside vegetation is the permanent erosion and sediment control material for preventing erosion and pollution of the surface runoff water. The vegetated roadside protects the soil surface and filters stormwater runoff from the pavement. This task documents the erosion control properties of new and existing plots.

Rainfall simulators were used to conduct the test (Figure 4). The simulator includes spray nozzles on top of 5-foot (1.52 m) risers mounted on a 20-foot (6.1 m) by 10-foot (3.05 m) rack. This was done to create the impact of water droplets on the soil surface. Each rack had a 5-foot (1.52 m) space in between to allow for maximum coverage.

(a) Simulated Rainfall Test on Field Plots (b) 5-foot Risers to Elevate Spray Nozzles

Figure 4. New Test Plot Rainfall Simulator.

Initial Testing

Prior to mowing, the erosion control performance of existing plots was measured using simulated rainfalls of 5.75 in/hr (146.1 mm/hr) intensity, the equivalent of a 2-year storm intensity. Soil moisture was measured before testing to ensure that moisture was within a reasonable range. Table 4 documents the soil moisture data. The duration of each test was 10 minutes and each plot was tested twice. Sediments washed off from the plots were collected in a concrete channel at the base of the slope and weighed after drying.

Final Testing

In the final year of the project, all plots (existing and new) in the project were tested using the same 2-year rainfall event equivalent and duration to document any changes in erosion control performance. Each plot was tested twice.

Table 4. Average of Soil Moisture Before Each Erosion Control Testing.

Plot	Date	Average Soil Moisture (%)		
		Top of Hill	Middle of Hill	Bottom of Hill
Existing 3:1 Sand (Five Plots)	10/21/2004	14.82	16.62	20.10
	10/26/2004	17.22	23.54	29.64
	11/17/2006	5.76	8.50	10.22
New 3:1 Sand (Six Plots)	11/03/2006*	7.00	10.00	15.98
Existing 2:1 Clay (Five Plots)	11/04/2004	35.92	35.28	33.38
	11/09/2004	24.96	28.32	34.58
	11/17/2006	12.26	13.52	18.26
New 3:1 Clay (Six Plots)	11/03/2006	26.72	30.15	34.23

* Plot 1 is not included to calculate the mean soil moisture because it was measured after the artificial rainfall test on 10/26/2006.

Mowing

In the field plot experiments, both existing and new, mowing was applied to half of each plot in accordance with TxDOT's regular mowing schedule and practice. Approximately 10 to 15 days prior to mowing, vegetation was identified on each plot as described under section "Existing Field Plot Monitoring Experiment." This was to examine the effect of mowing on vegetative communities and species diversity. A mower attached to a tractor was used (Figure 5a). The tractor moved along the slope direction to mow a 10-foot (half) strip of each plot (Figure 5b). The mowing height was set at 7 inches (0.18 m) above ground. This height allowed the hillside to experience the same treatment as a typical roadside, creating a situation in which researchers could observe the growth of successional vegetation. The entire mowing schedule for both new and existing plots is presented in Table 5.

(a) Mowing Done by Tractor

(b) Mowed Plots

Figure 5. Mowing Applied on Test Plots.

Table 5. Mowing Schedule*.

Date	Activities
12/15/2004	Existing Plots mowed
04/06/2005	New Plot Installation completed
07/29/2005	Existing plots mowed
11/29/2005	Existing and new plots mowed
07/03/2006	Existing and new plots mowed
12/14/2006	Existing and new plots mowed

* Grass species were identified 10 to 15 days prior to mowing.

Training Video

All the research tasks, including roadside studies and the field laboratory project, were periodically recorded with photographs or videos. The research team used these multimedia materials, along with findings and analytical results from the documentation process, to create a training video that can introduce this entire project to roadside vegetation managers. The Communications Program of TTI provided technical support to edit and produce the video. A video storyboard (see Appendix A) was developed and presented to TxDOT for comments and approval. Following the storyboard was the preparation of voiceover script and audio/video materials and video editing. The training video DVD is included in this report.

ASSESSMENT OF PRACTICE ADMINISTERED DURING THE PROJECT

SUMMARY OF TELEPHONE CONVERSATION WITH IOWA DEPARTMENT OF TRANSPORTATION

One of the pioneer departments of transportation in the use of native species on roadsides is the Iowa Department of Transportation (IDOT). To gather information regarding IDOT's methodologies and the current status of their native seed mix program, an assessment of practice through telephone was administered to IDOT representative Mark Mastellar in December of 2006. A summary of this telephone survey follows.

IDOT began using a 100 percent native seed mix on all seeded roadway projects in the early 1990s, and currently 176,000 total acres of roadsides are maintained by the IDOT within the state of Iowa. Of this, 40,000 acres have been seeded with native mixes, of which 10,000 acres are on rural rights-of-way.

Cost Issues

Installation costs are higher and range between $100/acre (with a basic grass mix) to $1000/acre (with flower mix) more than traditional grass mixes. Costs for non-native mixes range from $300 to $350/acre and from $450 to $500/acre for native mixes. Initially, seed availability was an issue but over a 2-year period local seed producers caught up to demand. Currently, IDOT has 16–17 seed suppliers to choose from.

Safety Issues

Positive:

IDOT has found that native grasses hold more snow and reduce drifting on the road surface. They also reduce blowing snow across road surfaces, reducing the cooling effect of snow and thus preventing icing. IDOT also has hypothesized that native grasses could have glare reducing effect on the drifted snow, thus reducing driver fatigue.

Neutral:

The Iowa Department of Natural Resources says that deer incidents are no greater for native vs. non-native rights-of-way.

Negative:

While driver visibility is still a contested issue that is being studied, IDOT has found no specific negative effects of driver safety related to the use of native vegetation on roadsides.

Maintenance Issues

IDOT has little documentation on cost differences pertaining to the maintenance of native vs. non-native seed mixes on roadsides. The following anecdotal information was provided:

- No new or additional equipment is required to seed or maintain.
- Establishment rate is slower, so weed control can be a problem.
- In Iowa native vegetation competes with thistle (a noxious weed of Iowa).
- IDOT uses a strip mow policy when necessary for native roadsides.
- Excessive brush or woody plants and weeds are controlled specifically on an as-needed basis.
- No other differences in mowing are used on native vs. non-native roadsides.

Additional Information

Additional information on IDOT's native roadside vegetation program can be found at www.iowalivingroadway.com.

SEED AVAILABILITY AND COST SUMMARY

Seed Supplier Survey

In order to determine the availability and cost of native grass seed, surveys were distributed in May 2004 to six seed companies with a list of the native grasses used for TxDOT research Project 0-5212 (McFalls et al., 2007). The surveys asked questions regarding general seed availability, seed availability from year to year, and cost. Four seed companies responded to the survey:

- Bamert Seed Co.,
- Douglas W. King Seed Co.,
- Native American Seed Co., and
- Turner Seed Co.

Several of the surveys were returned incomplete, providing varied results; therefore, only generalized summaries could be made regarding native seed cost and availability. Using the survey results and comments noted from conversations with representatives of various native seed companies, researchers were able to establish some general conclusions regarding availability and pricing of individual native grasses.

Seed Availability

While most of the native grasses were readily available, seeds of several of the native grasses on the list were considered difficult to obtain. Among those grasses were *Aristida purpurea,* Purple Threeawn; *Stipa leucotricha,* Texas Wintergrass; *Elymus elymoides,* Bottlebrush Squirreltail; *Andropogon glomeratus*, Bushy Bluestem; *Oryzopsis hymenoides,* Indian Ricegrass; and *Muhlenbergia wrightii,* Spike Muhly. In addition to harvest difficulties, producers have stated the availability of these grasses is low because of little demand.

Many of the large seed suppliers grow and harvest the majority of their own seed. The native seed varieties that are typically in high demand from year to year are grown in fields owned by the seed company or by contract growers. The native grasses that have lower demand are typically obtained through other companies or the native seed supplier will try to find established plots of that particular species and arrange contracts for harvest. Many native seed varieties and mixes come from fields where a seed supplier has negotiated an arrangement to harvest native stands of grasses and forbs.

The availability of native seed is largely determined by the demand for that seed. Representatives from native grass seed companies argued, true or not, that species would become more readily available if TxDOT were to write specifications for the use of a particular native grass currently with little demand. This is, of course, dependent on an adequate supply of the grass readily available for harvest. Even so, however, according to the seed suppliers, even with uncommon varieties of native grasses, if demand was there for a seed, the companies would find ways to make it available.

Seed Cost Variabilities

The individual cost of native grass seed varies considerably from species to species; however, there seems to be a correlation between price and demand. As a general rule, the higher the production the lower the price. The Texas Bluebonnet is an example of a native species that first entered the commercial market at a price of approximately $30/lb and as production and availability increased the price per pound went down to the current price of approximately $7/lb.

The seed cost chart below supports the fact that the initial cost of the more difficult to obtain and low demand native seeds is higher than those of more commonly used native grasses. According to Jay Kane at Native American Seed, current seed prices (2004) for commonly sold seeds are at an all-time low. Kane noted that prices fluctuate and are closely tied to the Conservation Reserve Program. He noted that a historic benchmark for seed prices fluctuated between $10/lb and $15/lb. Short-term changes in price for a seed no longer in demand or suddenly in demand could range up or down 270 percent.

Seed Cost Chart as of May 2004

Name of Seed	Cost	Unit
Sporobolus airoides, Alkali Sacaton	$9.50	LB
Bouteloua gracilis **‘**Hachita,’ Blue Grama ‘Hachita’	$7.00	LB
Buchloe dactyloides, Texoka Buffalograss	$5.00	LB
Sporobolus cryptandrus, Sand Dropseed	$4.00	LB
Hilaria jamesii, Galleta ‘Viva’	$16.00	LB
Schizachyrium scoparium*,* Little Bluestem	$7.50	LB
Andropogon hallii, Sand Bluestem	$5.00	LB
Bouteloua curtipendula, Sideoats Grama ‘El Reno’	$3.25	LB
Leptochloa dubia*,* Green Sprangletop	$4.50	LB
Eragrostis trichodes*,* Sand Lovegrass	$4.00	LB
Setaria macrostachya, Plains Bristlegrass	$9.00	LB
Desmanthus illinoensis, Illinois Bundleflower	$4.00	LB
Eragrostis curvula, Weeping Lovegrass ‘Ermello’	$9.00	LB
Cassia fasciculate*,* Partridge Pea	$11.00	LB
Petalostumum purpureum, Purple Prairieclover	$22.00	LB
Cynodon dactylon, Common Bermudagrass	$6.25	LB
Stipa leucotricha*,* Texas Wintergrass	$75.00	LB
Native Coastal Prairie Mix*	$39.00	LB
Aristida purpurea*,* Purple Three-Awn	$49.95	LB
Andropogon glomeratus*,* Bushy Bluestem	$89.00	LB
Coreopsis lanceolata*,* Lanceleaf Coreopsis	$18.50	LB

*(The current harvest [2004] contains Little Bluestem, Split Beard Bluestem, Big Bluestem, Broomsedge Bluestem, Balsamgrass, Florida Paspalum, Red Lovegrass, Tall Dropseed, Scratch Dropseed, Slender Paspalum, Knotroot Bristlegrass, Wild Indigo, Croton Gayfeahter, Sunflower, Ragweed, Wild Bean, Gaura, Indiangrass, Three Awn spp., Purpletop, Aster, Vervain, Switchgrass, Marsh Elder, and Partridge Pea.)

Concluding Remarks

The majority of the native grasses used for this TxDOT research project are available in large quantities. The few grasses that are not readily available are not currently harvested in great amounts due to lack of demand or the species is not as readily available. If demand increases for these grasses, the production and availability should also rise and the corresponding cost should decrease.

RESULTS

ROADSIDE VEGETATION SURVEY

The variations in plant composition observed on actual highways was, of course, quite high. However, it was clear the present vegetation community was much more diverse than the standard TxDOT seeding mixture. In many locations, annual and perennial herbaceous species comprised significant portions of the vegetation.

A few species were present in many of the surveyed areas. These included:

- Silver Bluestem (*Bothriochloa saccharoides*)
- Johnsongrass (*Sorghum halepense*)
- White Tridens (*Tridens albescens*)
- Bermudagrass (*Cynodon dactylon*)
- K.R. Bluestem (*Andropogon ischaemum*)
- Bahiagrass (*Paspalum notatum*)

The roadsides in the Corpus Christi District were less species-diverse, typically containing only Bermudagrass but with some significant sections of Indiangrass, Silver Bluestem, and Johnsongrass. The connection between roadside composition and the vegetation immediately outside the right-of-way was quite noticeable in these corridors. Most lands in this area were in active grazing or were formerly grazed lands. The dominant vegetation in these pastures is Bermudagrass.

On the other hand, SH47 in the Bryan District contained a wide variety of herbaceous forbs that in some places comprised a significant portion of the total cover. Observed vegetation species including annuals/perennials, grass, shrubs, and trees are tabulated in Appendix B. The range of this diversity can be quite significant. Each survey station contained approximately 30 to 40 out of 77 total named species. This survey result indicates the significant contribution that forbs make to the overall composition of the roadside. It should also be noted that with the exception of a few of the wildflower species, none were seeded into the roadside. With the exception of Little Bluestem and Sideoats Grama, all the native grasses were also volunteers.

The researchers specifically focused on grass species because grasses play a critical role in roadside revegetation efforts. The grasses were closely assessed. Results of the roadside grasses on FM 70 in Corpus Christi and SH 47 in Bryan are presented in Tables 6 and 7, respectively. The percentages represent the estimation of the individual species coverage for each site observation. It should be noted that the total percentage of identified grass species typically exceeds 100 percent. This is because different grasses may have different heights and overlap each other in the same space.

The survey results indicate that rare native grasses were observed within the roadside rights-of-way. Fewer natives were found on front slopes, as compared to short sod-forming non-natives that were frequently observed. Back slopes had a greater variety of different species, and some natives were found. The difference of grasses between front and back slopes is demonstrated in Figure 6.

It should be noted that full-width mowing on the entire right-of-way typically occurs two to three times per year. Meanwhile, there are typically two additional instances of “strip” mowing that only covers the 15-foot (4.6 m) front slope areas near the pavement each year. Such a subtle difference in mowing frequency was found to affect the roadside grasses, and progressive changes can be observed between the front and back slopes (Tables 6 and 7). Figure 7 illustrates a roadside example that demonstrates the mowing effect on grasses.

Another important observation is the consistent dominance on the front slopes of both FM 70 and SH 47 of common Bermudagrass (*Cynodon dactylon*), an introduced sod-forming grass. Such dominance of Bermudagrass decreased on the back slopes. Obviously Bermudagrass became less competitive than natives on less or undisturbed environments. In other words, no invasiveness can be concluded on Bermudagrass. In addition, ryegrass (*Lolium perenne L.*) and K.R. Bluestem (*Andropogon ischaemum*), both considered as introduced short grasses, were also observed in significant amounts on SH 47.

The original soil type appears to have no obvious effect on the roadside grasses in terms of the dominant species. This can be intuitively attributed to the different roadside soil conditions altered by the roadway construction.

Table 6. Average Cover Percentage of Dominant Grasses and Soil Types on FM 70.

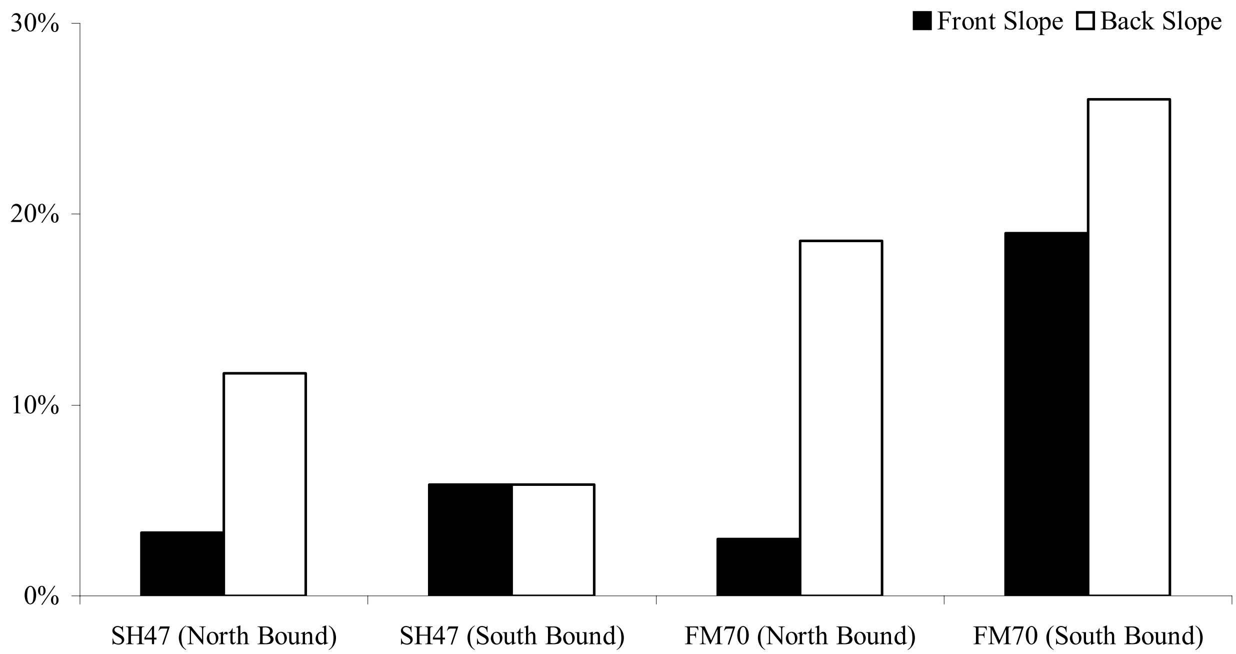
Graminoid Species				1 Loamy Sand**		2 Loamy Sand		3 Loamy Sand		4 Loamy Sand		5 Clay	
Botanical	**Common**	**US Nativity**	**Height ***	**F*****	**B**	**F**	**B**	**F**	**B**	**F**	**B**	**F**	**B**
North Bound													
Panicum virgatum	Switchgrass	N	T	15	85	-	-	-	5	-	1	-	-
Setaria leucopila	Streambed Bristlegrass	N	S	-	-	-	-	-	1	-	1	-	-
Andropogon ischaemum	K.R. Bluestem	I	S	-	-	-	70	-	10	-	20	-	-
Cynodon dactylon	Bermudagrass	I	S	85	15	100	30	100	95	100	90	90	50
Sorghum halepense	Johnsongrass	I	T	-	-	-	-	-	-	-	1	-	10
South Bound													
Panicum virgatum	Switchgrass	N	T	90	70	-	-	5	40	-	-	-	-
Setaria leucopila	Streambed Bristlegrass	N	S	-	-	-	-	-	10	-	-	-	10
Andropogon ischaemum	K.R. Bluestem	I	S	-	-	-	70	-	10	-	20	-	-
Cynodon dactylon	Bermudagrass	I	S	10	30	100	100	100	20	100	50	100	50
Sorghum halepense	Johnsongrass	I	T	-	-	-	-	-	15	-	-	-	10

* N: Native, I: Introduced, T: Tallgrass, S: Shortgrass, height greater than 18 inches (46 cm) is considered as tall; otherwise, short.
** Original soil type of survey station.
Note: Numerical values shown are a visual estimate of how much of the area a species has a noticeable presence as a definable plant group. The amounts do not reflect a percent of the vegetated cover of a site. If no value is shown, the species was not noticeably present but may still occur as isolated individuals.
*** F: front slopes; B: back slopes.

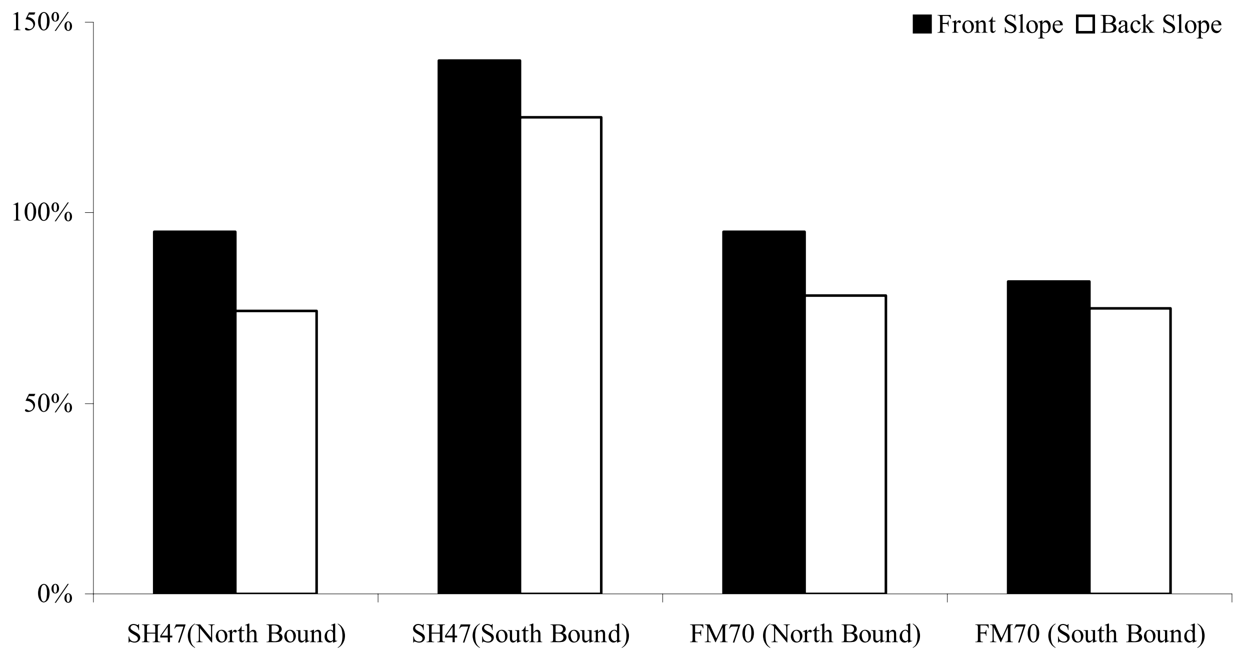
Table 7. Average Cover Percentage of Dominant Grasses and Soil Types on SH 47.

Graminoid Species				1 Sand**		2 Loam		3 Loam		4 Loam		5 Sandy Loam		6 Sandy Loam	
Botanical	**Common**	**US Nativity**	**Height ***	**F*****	**B**	**F**	**B**	**F**	**B**	**F**	**B**	**F**	**B**	**F**	**B**
North Bound															
Aristida oligantha	Oldfield Threeawn	N	S	-	-	-	-	-	-	-	-	-	20	-	-
Bothriochloa saccharoides	Silver Bluestem	N	T	-	-	-	-	-	10	-	-	-	-	-	-
Chloris verticillata	Windmillgrass	N	S	10	-	-	-	-	-	-	-	-	-	5	-
Stipa leucotricha	Texas Wintergrass	N	S	-	40	-	-	-	-	-	-	-	-	-	-
Tridens albescens	White Tridens	N	T	-	-	-	-	-	-	-	-	-	-	5	-
Andropogon ischaemum	K.R. Bluestem	I	S	20	20	30	-	10	-	80	50	10	5	20	30
Bromus inermis	Smooth Brome	I	S	-	-	-	-	5	-	-	-	-	-	-	-
Cynodon dactylon	Bermudagrass	I	S	5	20	80	10	80	-	-	-	70	20	10	50
Eustachys retusa	Argentine Fingergrass	I	T	-	-	10	-	-	-	-	-	10	-	-	-
Lolium perenne	Perennial Ryegrass	I	S	5	50	50	50	20	40	-	-	-	-	50	50
Paspalum notatum	Bahiagrass	I	S	-	-	-	-	-	30	-	20	-	-	-	-
Sorghum halepense	Johnsongrass	I	T	-	-	-	-	5	-	-	-	-	-	-	-
South Bound															
Aristida oligantha	Oldfield Threeawn	N	S	-	10	-	-	-	-	-	-	-	-	-	-
Bothriochloa saccharoides	Silver Bluestem	N	T	-	-	5	10	-	-	-	-	-	-	-	10
Chloris verticillata	Windmillgrass	N	S	20	-	-	-	-	-	-	-	-	-	-	-
Paspalum plicatulum	Brownseed Paspalum	N	T	-	-	-	-	-	-	-	-	5	-	-	-
Tridens albescens	White Tridens	N	T	5	5	-	-	-	-	-	-	-	-	-	-
Andropogon ischaemum	K.R. Bluestem	I	S	10	10	-	-	-	-	-	-	10	10	90	-
Cynodon dactylon	Bermudagrass	I	S	80	50	70	10	100	5	90	30	90	10	30	10
Eustachys retusa	Argentine Fingergrass	I	T	5	-	-	-	-	-	-	-	-	-	-	-
Lolium perenne	Perennial Ryegrass	I	S	60	60	60	90	30	30	40	100	10	90	5	5
Paspalum notatum	Bahiagrass	I	S	20	-	-	-	5	100	-	-	20	50	10	70
Sorghum halepense	Johnsongrass	I	T	-	-	5	10	-	-	-	-	-	-	-	10

* N: Native, I: Introduced, T: Tallgrass, S: Shortgrass, height greater than 18 inches (46 cm) is considered as tall; otherwise, short.
** Original soil type of survey station.
Note: Numerical values shown are a visual estimate of how much of the area a species has a noticeable presence as a definable plant group. The amounts do not reflect a percent of the vegetated cover of a site. If no value is shown, the species was not noticeably present but may still occur as isolated individuals.
*** F: front slopes; B: back slopes.



(a) Native species



(b) Introduced species

Figure 6. Grasses on Front and Back Slopes of FM70 and SH47.

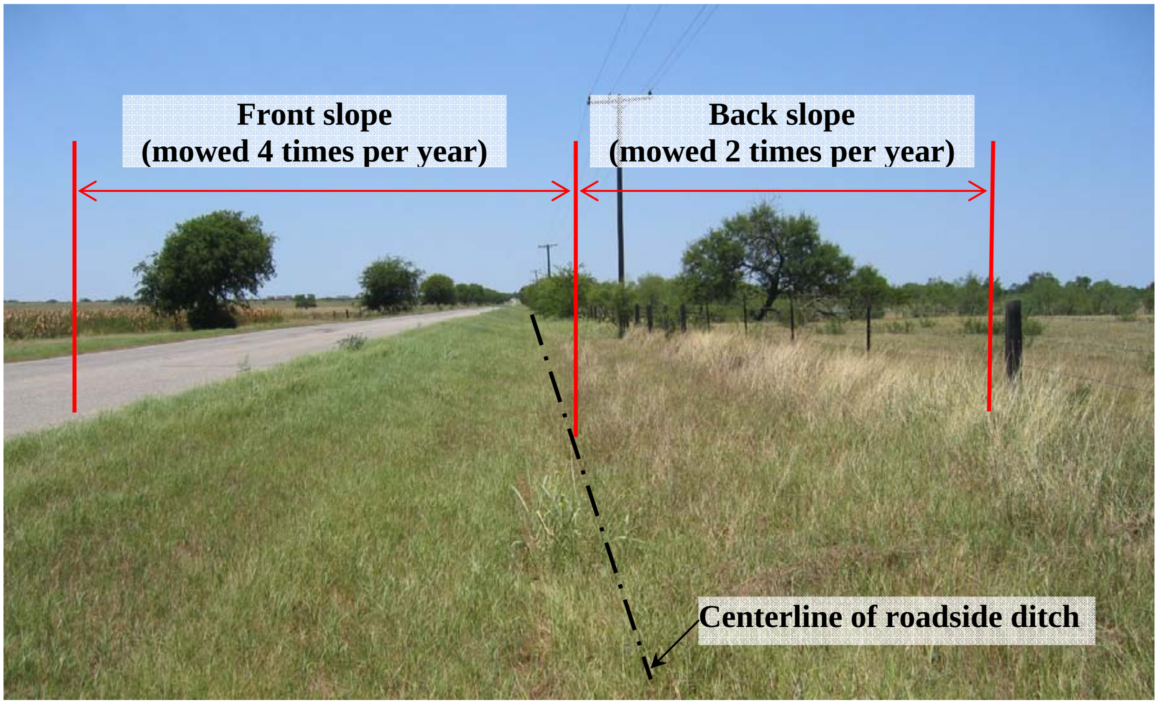


Figure 7. Mowed Roadsides Showing Mowing Effect on Grasses between Front and Back Slopes.

In addition, photos of surveyed roadsides are documented on the CD-ROM included in this report. For each survey station, an isometric illustration of the roadside condition is shown in the center of the drawing with photographs taken at the station. Photographs may show conditions along the highway and surrounding land use. A highway map of the surveyed segment superimposed on top of USDA's soil survey is also included. All drawing sheets are in the portable document format (PDF) and can be viewed with Adobe Reader ®.

Field Experiment on Existing and New Test Plots

Successional Change Observation

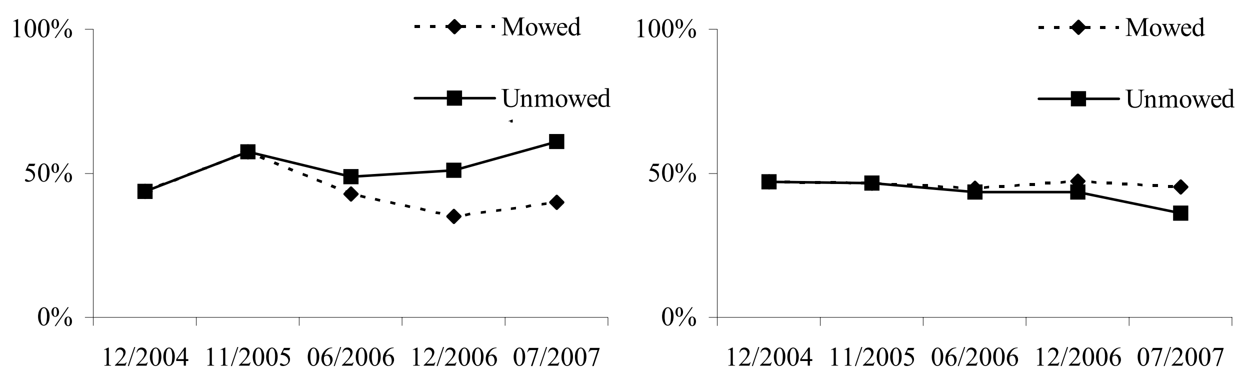
The original field survey records are documented in Appendix C. Note that average cover percentage of dominant grass species was recorded using six categories for existing and new plots. The ranges in percentage of each category are listed below:

- I: 0-5 percent
- II: 6-20 percent
- III: 21-50 percent
- IV: 51-80 percent
- V: 81-95 percent
- VI: 95-100 percent

To aid the analysis on succession, the researchers plotted figures of cover percentage versus time. In this analysis, the middle value of the range in each category (listed above) was used to represent the average cover of that category as listed below:

- "2.5" for I: 0-5 percent
- "13" for II: 6-20 percent
- "35.5" for III: 21-50 percent
- "65.5" for IV: 51-80 percent
- "88" for V: 81-95 percent
- "97.5" for VI: 95-100 percent

The overall results from existing plots (combining sand and clay plot results) indicate that when no mowing was applied, native grasses gradually increased (Figure 8a) whereas introduced grasses decreased (Figure 8b). However, the increased trend of native grasses was affected by mowing as indicated by the "mowed" curve in Figure 8a. Mowing apparently suppressed natives' growth and the difference of natives' cover percentage between mowed and unmowed areas widened over time. On the other hand, mowing seemed to allow introduced grasses to maintain their constant coverage, but did not have as much affect when compared with natives (Figure 8b).

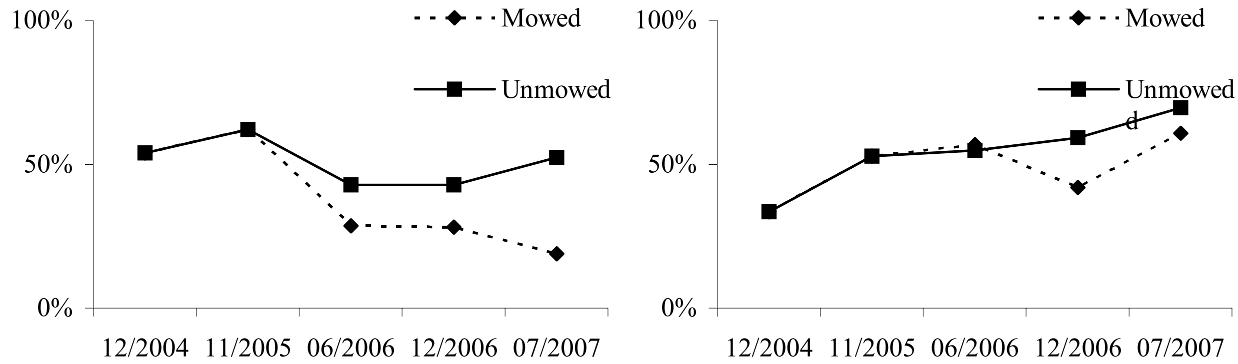


(a) Native Grasses

(b) Introduced Grasses

Figure 8. Combined Average Cover Percentage of 10 Existing Plots.

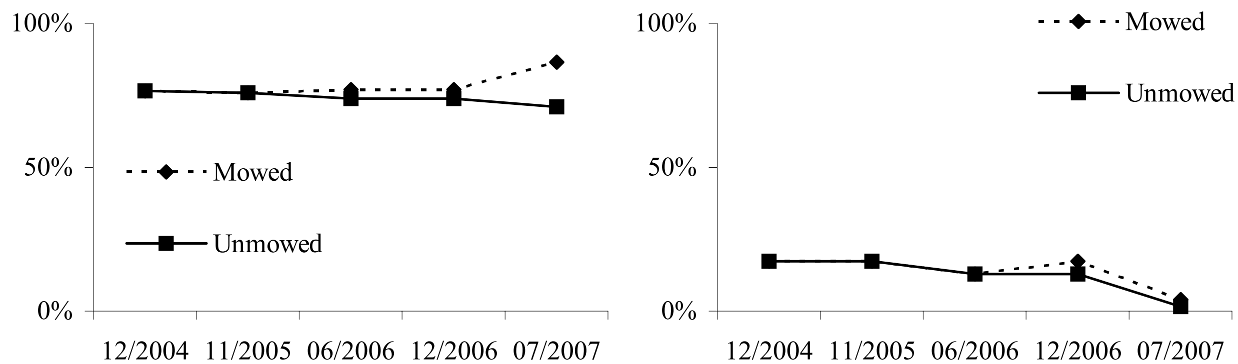
When the factor of soil type was considered, natives on sand (Figure 9a) seemed to underperform those on clay (Figure 9b) over time. Also, mowing apparently suppressed native species growth and mowing had a greater impact on natives growing on sand (Figure 9a) than those on clay (Figure 9b).



(a) Native Grasses on Sand (b) Native Grasses on Clay

Figure 9. Native Grass Average Cover Percentage of 10 Existing Plots.

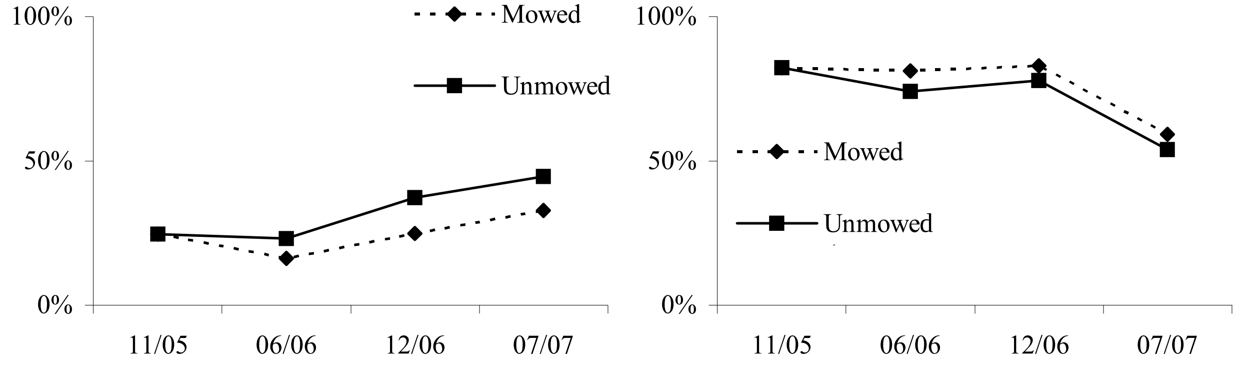
On the other hand, a higher coverage by introduced grasses was observed more on sand than on clay (Figure 10). Also, mowing seemed to increase introduced grasses, and this effect was more significant on sand (Figure 10a) than on clay (Figure 10b).



(a) Native Grasses on Sand (b) Native Grasses on Clay

Figure 10. Introduced Grass Average Cover Percentage of 10 Existing Plots.

The overall results from new plots (also combining sand and clay plot results) indicate that native grasses gradually increased (Figure 11a) whereas introduced grasses decreased (Figure 11b). In addition, native grasses had a greater cover percentage on unmowed areas than on mowed areas while introduced grasses showed an opposite result. This finding was attributed to clay plot observations by examining the results between sand and clay plots. As shown in Figure 12, mowing did not affect either native or introduced grasses on sand plots but significantly altered the cover percentage on grasses growing on clay plots.



(a) Native Grasses (b) Native Grasses

Figure 11. Combined Average Cover Percentage of 12 New Plots.

The researchers also observed a large difference of cover percentage between native and introduced species on sand (Figure 12a and 12b) but a relatively small one on clay (Figure 12c and 12d). This was perhaps due to the drought encountered at the HSECL during the first year of planting on the new plots in the summer of 2005. Seeds applied on clay plots that could hold more water likely would have better germination rates whereas seeds on sand plots that dried out completely during the summer 2005 drought were more likely to have died. Table 4 shows the soil moisture data prior to each erosion control testing, which clearly demonstrated large differences between sand and clay plots.

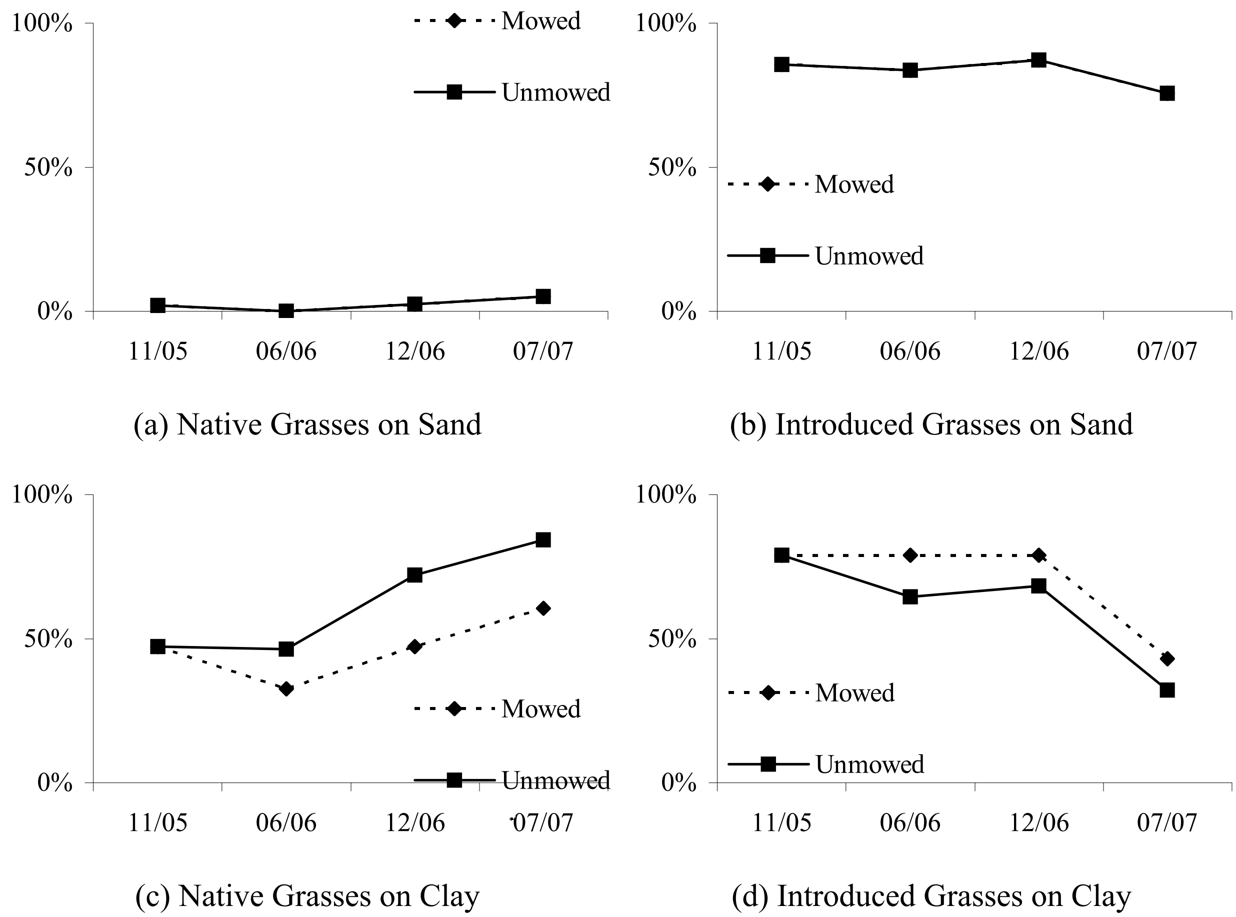


Figure 12. Average Cover Percentage of 12 New Plots.

Close examination of the results from the laboratory experiments and roadside surveys reveals that mowing on laboratory plots did not affect grass composition as much as that of the actual roadsides. As previously mentioned, fewer natives with less cover percentage were found on front slopes, as compared to short sod-forming non-natives that were frequently observed. Additionally, back slopes had a greater variety of different species, and some natives were found. In addition, much higher species numbers were observed on actual roadsides. Each survey station contained approximately 30 to 40 out of 77 total named species (see Appendix D.1). The number of species found on laboratory plots was only 38 (Appendix D.2).

The researchers attributed this to two major factors. First, the frequency of mowing applied to laboratory experiment plots and actual roadsides was different. Because experimental plots were never mowed more than three times per year during the entire research project (see mowing schedule in Table 5), the mowing experiment was simulating the "back slope" condition of actual roadsides. Therefore, disturbance by mowing done on laboratory plots might not impact the grass composition as much as that of the front slopes of highway roadsides. Second, the condition of adjacent lands between laboratory plots and roadsides were not equal. Actual roadsides were adjacent to diverse environmental, natural, or managed lands that served as seed banks in which more species could be provided.

In summary, despite the difference between laboratory plots and actual roadsides, the results from the field experiments conducted in HSECL are consistent with the observations from the roadside vegetation survey on actual highways.

The researchers also compared surviving species resulting from the original seed mix and original seeded species. A summary of the number of species is presented in Table 8. Common and botanical names of surviving and seeded species are documented in Appendix D. It was found that very few original seeded species were still surviving when the vegetation survey was conducted (Table 8). However, a high number of native species were identified on both existing and new plots. The species diversity on existing plots was higher than those observed on new ones. In addition, none of the seeded species, both TxDOT seed mixes and non-TxDOT seed mixes, was found to be invasive.

Table 8. Comparison Between Planted and Observed Species.

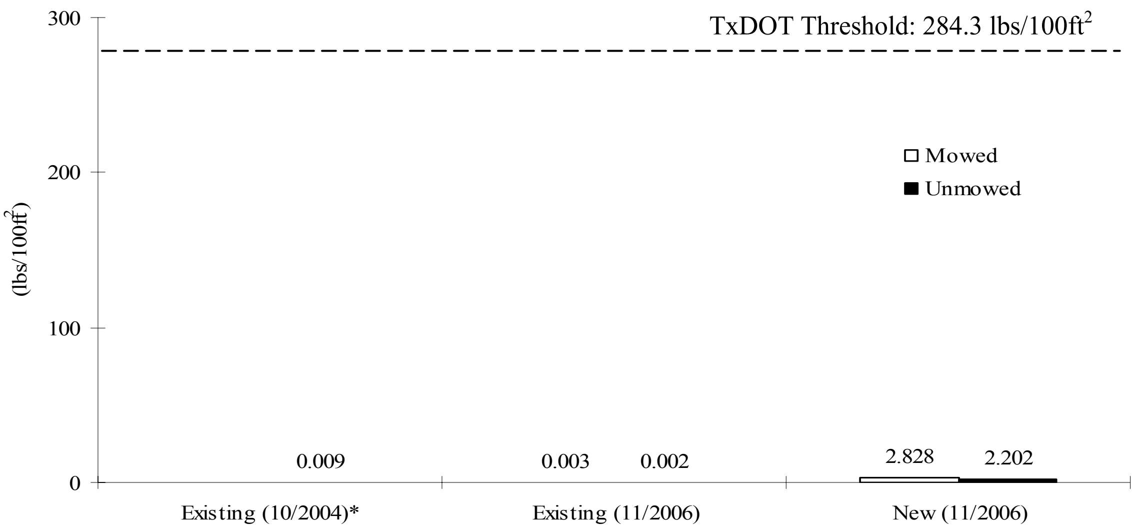
Experiment Plots	Number of Seeded Species in the Original Seed Mix	Number of Surviving Species from the Original Seed Mix	Total Number of Observed Species
Existing Plots			
Crownvetch	1	0	23
Native Forbs	19	3	23
Wildflower Mix	25	1	21
Native Grasses	7	3	19
Control (Bermuda Only)	1	0	24
New Plots			
Sand	6	3	13
Clay	5	2	16

Erosion Control Testing

Table 9 presents results of erosion control testing in the laboratory setting. It can be observed that regardless of the slope, soil type, or mowing practices, each plot of vegetation yielded soil loss well below the TxDOT's minimum performance standards, also called "thresholds" (TxDOT, 2000). The large differences between tested plots and the thresholds are clearly illustrated in Figure 13. It should be noted that the thresholds were the pass-and-fail criteria used by TxDOT to approve or disapprove erosion control products. Products passing the thresholds are listed in the "Approved Products List." There were no significant differences in sediment loss between mowed and unmowed plots. As expected, sand plots lost slightly more sediment than clay plots. The most significant trend was that existing plots (vegetated since 2004) had nearly no detectable sediment loss regardless of soil type or slope, whereas the newer plots had sediment losses ranging from 0.16 to 2.83 lb/100 ft^2. Detailed testing data are documented in Appendix F.

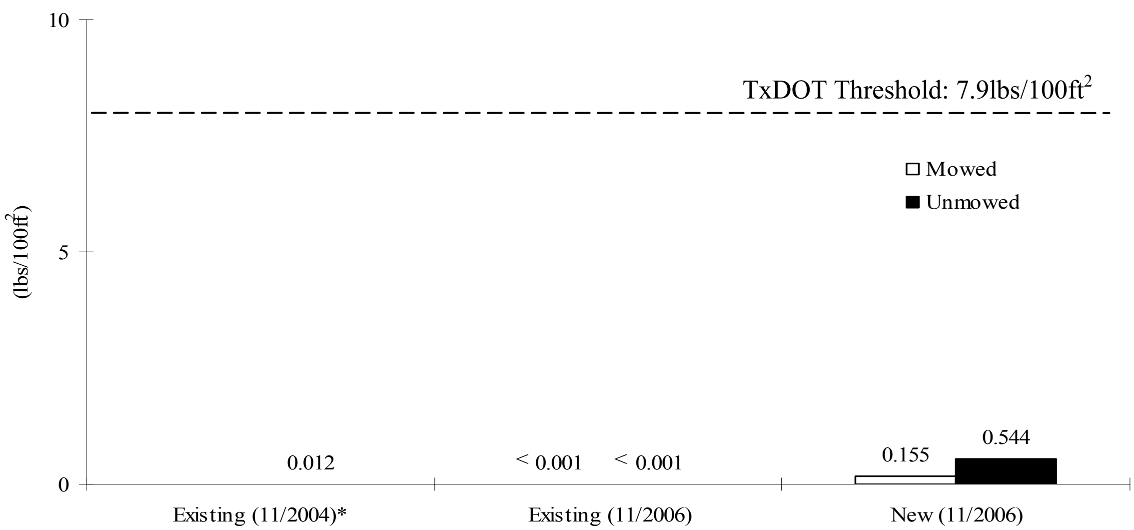
Table 9. Erosion Control Testing Results (Mean Sediment Loss in lb/100 ft^2).

Plot	Date	Flow Rate (GPM)	Avg. Dry Loss (lb/100 ft^2)		
			TxDOT Thresholds	Mowed	Unmowed
Existing 3:1 Sand	10/21/2004	78.9	284.3	-	0.005
	10/26/2004	78.9		-	0.013
	11/17/2006	78.9		0.003	0.002
New 3:1 Sand	10/26/2006 11/03/2006	78.9	284.3	2.828	2.202
Existing 2:1 Clay	11/04/2004	52.6	7.9	-	0.016
	11/09/2004	52.6		-	0.008
	11/17/2006	52.6		<0.001	<0.001
New 3:1 Clay	10/26/2006 11/03/2006	78.9	7.9	0.155	0.758



* the average of two erosion tests on 10/21/2004 and 10/26/2004

(a) Sand Plots



* the average of two erosion tests on 11/04/2004 and 11/09/2004

(b) Clay Plots

Figure 13. Erosion Control Testing Results.

Mowing Effect

In the section “Roadside Vegetation Survey” of the “Results” Chapter, the effect of mowing on actual highway roadsides has been reported and discussed. In brief, roadside grass composition was affected by mowing, with the greatest effects linked to the mowing frequency. Full-width mowing on the entire right-of-way (front and back slopes) typically occurs two to three times per year. Additional “strip” mowing that only covers the 15-foot (4.6 m) front slope areas near the pavement adds at least two more mowings each year. Such a subtle difference in mowing frequency was sufficient to affect the roadside grass composition. As presented in Tables 6 and 7, progressive grass composition changes can be observed between the front and back slopes. The mowing effect observed on laboratory experiments is in agreement with that observed on actual roadsides. Details of comparison have been described in section “Field Experiment on Existing and New Test Plots.”

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This research project investigated the successional establishment, mowing response, and erosion control characteristics of vegetation used on roadsides. Several conclusions are described below:

- No grass species listed in TxDOT's standard seed mixes was observed as invasive. In areas less disturbed by mowing, native grasses gradually took over and introduced species in TxDOT's seed mixes became hardly noticeable.
- Bermudagrass (*Cynodon dactylon*), an introduced sod-forming grass, was found to be a dominant species on front slopes of both FM 70 and SH 47. However, the dominance of Bermudagrass decreased on the back slopes toward the right-of-way boundary. Bermudagrass became less competitive with native species on less disturbed or undisturbed environments. Within the scope of this project, Bemudagrass was not found invasive.
- Few, if any, of the seeded species were observed in established roadsides or laboratory test plots years after seeding. Volunteer species (i.e., those not from the original seed mixes) were found to be dominating roadsides in the long term.
- Mowing frequency resulted in different compositions of roadside grasses. Short, sod-forming grasses were adapted to zones more frequently mowed (about 3~4 times a year) and became less competitive on less frequently mowed areas. Tall native grasses were not adapted to frequently mowed areas. However, in areas left unmowed, tall native grasses gradually increased whereas introduced grasses decreased. Thus, roadside mowing makes a specific group of plant populations adaptable to roadsides and most of these adapted species are not natives.
- Laboratory experimental plots, new or existing and mowed or unmowed, showed a significant variety of plant species, meaning that highway roadsides can be rich in plant diversity and mowing maintenance may not necessarily decrease plant diversity.
- All field laboratory plots controlled erosion very well. Regardless of the slope, soil type, or mowing practices, each plot of vegetation yielded sediments much less than the TxDOT's allowable amounts.
- Few studies were found on cost and benefit analysis about roadside management as a result of a lack of consistent cost data held by state DOTs. Recommended research direction on cost and benefit of roadside management is provided in the subsequent subsection.

RECOMMENDATION

None of the grass species examined in this project were found to be invasive. Therefore, the research team does not recommend any changes to the district seed mix investigated in this project.

RECOMMENDED PROBLEM STATEMENT

Problem Statement

Long-term cost and benefit information about maintaining roadsides for native plants.

Research Problem Statement

The ecological benefits of establishing and maintaining native plants on highway roadsides are well documented. However, there are little or no data about the economics of maintaining native plant roadsides. Empirical evidence suggests that since less mowing and less herbicide applications are necessary for native roadsides compared with conventional roadside agricultural grasses, substantial savings should result. Again, no such data are published in current literature. The purpose of the research is to establish a database for roadside maintenance cost that can be used to compare cost and benefit associated with different uses of vegetation on roadsides. The research objectives are to compile available national cost data about roadside maintenance and develop cost and benefit indices for roadside management (native only or conventional programs).

Who Will Benefit from This Future Research?

Because of the Executive Order 13112 of February 3, 1999, on Invasive Species (Federal Register, 1999), all state DOTs are impacted. Not only TxDOT will benefit from the new research results but so will all DOTs in the United States.

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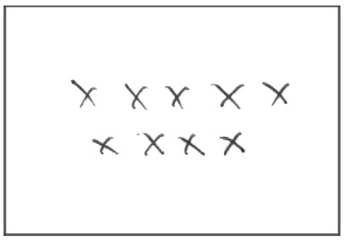
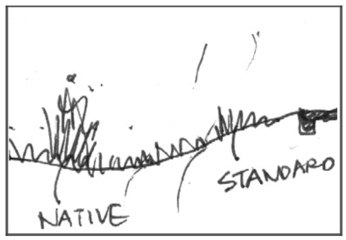
APPENDIX A. TRAINING VIDEO STORYBOARD

PART I. Background and Significance of Work (00:00-00:25)

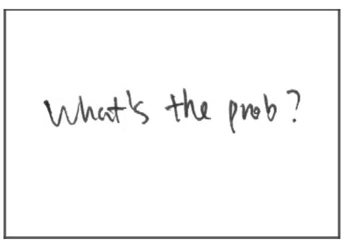


00:00-00:05

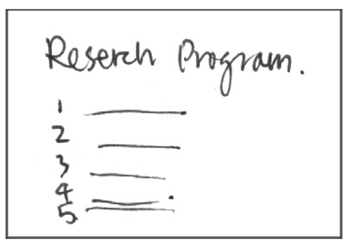


00:05-00:25

PART II. Objective (00:25-01:15)

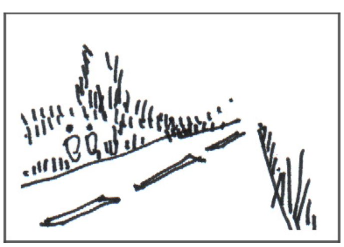


00:25-00:50



00:50-01:15

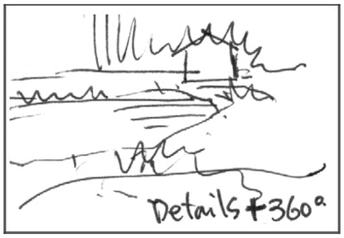
PART III. Roadside Vegetation Document (01:15-01:45)



01:15-01:45

PART IV. The Field Lab Testing (01:45-09:10)

1. HSECL Environment

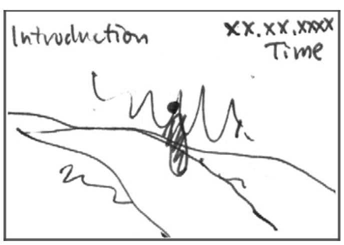


01:45-02:45

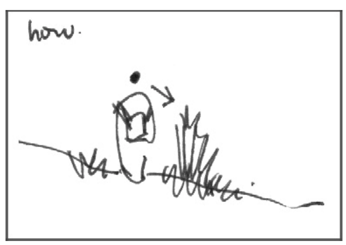
2. People

02:45-03:00

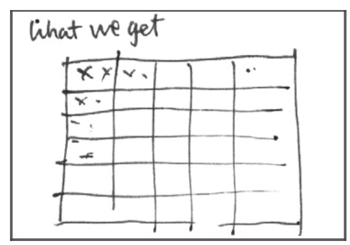
3. Process
   1) Inventory existing plots



Introduction 03:00-03:20

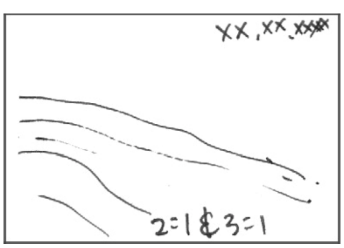


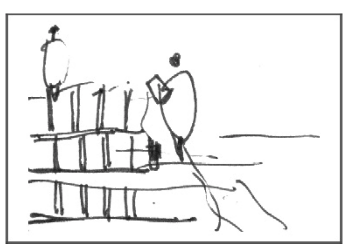
How 03:20-03:40

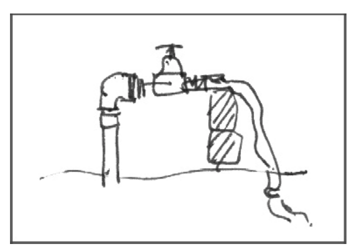


What we get 3:40-04:00

   2) Rainfall test on existing plots

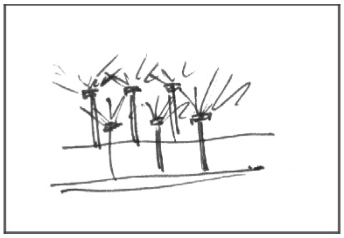




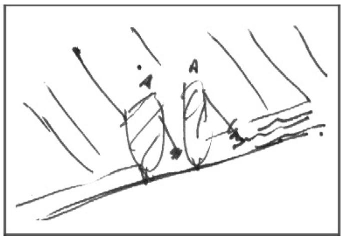


Introduction 04:00-04:15

Preparing 04:15-04:40

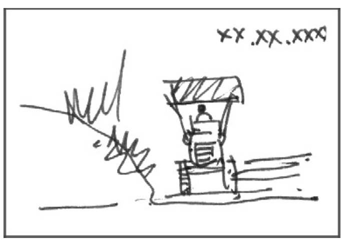


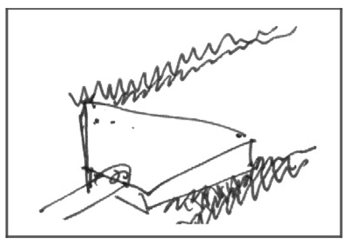
Testing 04:40-05:10



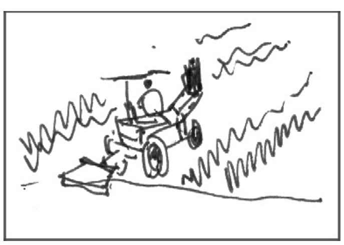
Closing 05:10-05:30

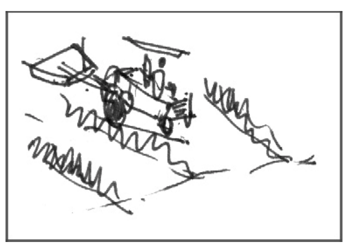
3) Mowing the existing site



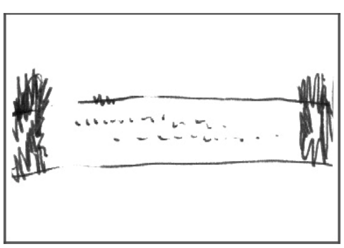


Introduction 05:30-05:45



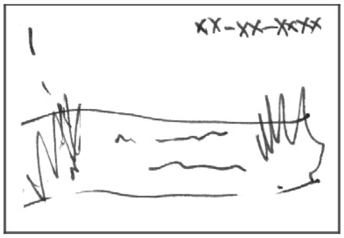


Mowing 05:45-06:10

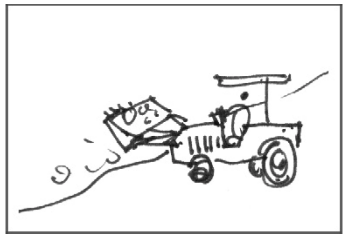


After mowing 06:10-06:15

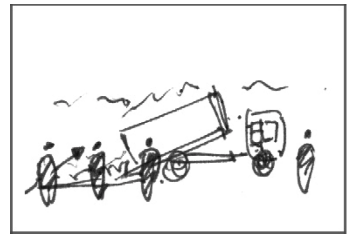
4) Preparing new plots



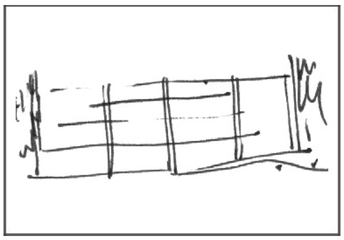
Introduction 06:15-06:20



Clean 06:20-06:35

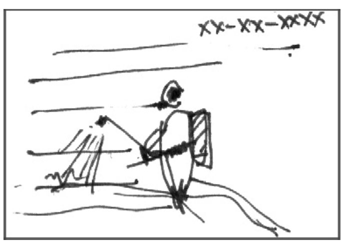


Fill 06:35-06:55

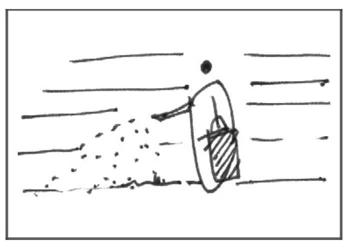


AFTER 06:55-07:00

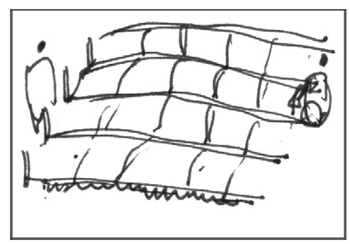
5) Plant new plots



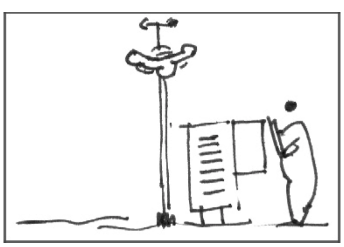
Sterilization 07:00-07:10



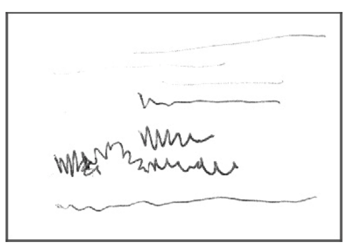
Replant 07:10-07:20



Blanket 07:20-07:30

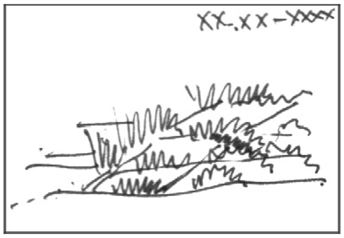


Collect climate data 07:30-07:40

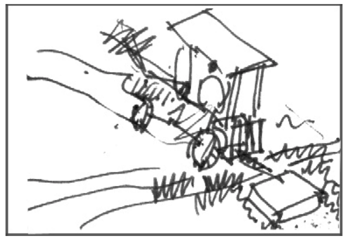


90 days after 07:40-07:45

6) Mowing new plots

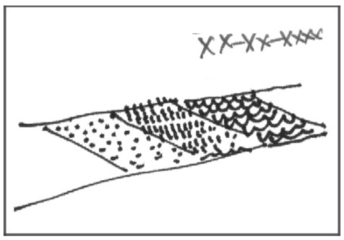


Introduction 07:45-07:55

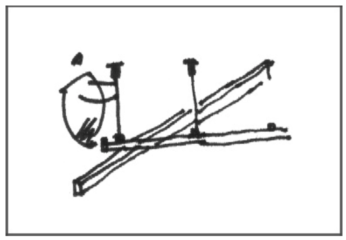


Mowing 07:55-08:05

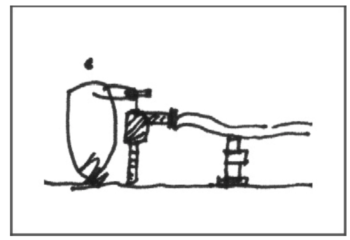
7) Rainfall testing on new plots

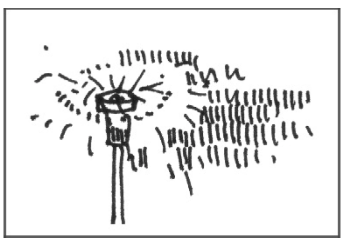


Introduction 08:05-08:10

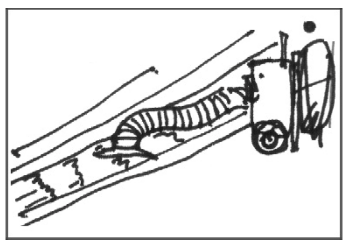


Preparing 08:10-08:30



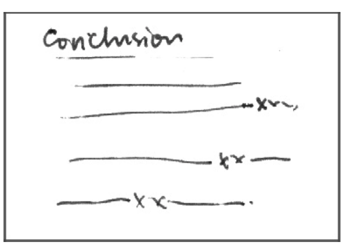


Testing 08:30-08:09:00

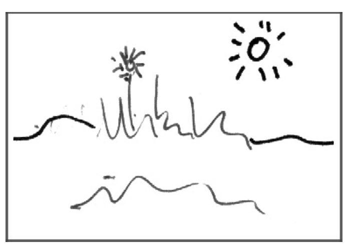


Closing 09:00-09:10

PART V. Conclusion (09:10-10:00)



Summary 09:10-09:30



Future opportunity 09:30-10:00

APPENDIX B. OBSERVED VEGETATION SPECIES (GRASS, FORBS, SHRUBS, AND TREES) ON SH47

Botanical Name	Common Name	1 SB	2 SB	3 SB	4 SB	5 SB	6 SB	1 NB	2 NB	3 NB	4 NB	5 NB	6 NB
Grasses - Native													
Aristida oligantha	Oldfield Threeawn	■						■				■	
Hordeum pusillum	Barley	■	■		■			■		■			■
Bothriochloa laguroides	Silver Bluestem	■	■			■	■	■	■	■	■	■	■
Bouteloua curtipendula	Sideoats Grama							■					
Bouteloua rigidesta	Texas Grama							■					
Chloris verticillata	Windmillgrass	■					■	■					■
Dichanthelium oligosanthes	Scribner’s Panicum							■	■	■	■		
Digitaria cognata	Fall Witch Grass							■					■
Nassella leucotricha	Texas Wintergrass	■						■		■			■
Paspalum plicatulum	Brownseed Paspalum	■		■		■	■	■	■	■			■
Schizachyrium scoparium	Little Bluestem									■			
Setaria parvifolia	Knot-root Bristlegrass										■		
Tridens albescens	White Tridens	■	■			■							■
Grasses - Introduced													
Avena fatua	Wild Oats								■	■			■
Bromus japonicus	Japanese Brome	■	■		■	■		■	■	■		■	
Lolium perenne	Perennial Ryegrass	■	■	■	■	■	■	■	■	■	■	■	■
Bothriochloa ischaemum	K.R. Bluestem	■	■	■		■	■	■		■	■	■	■
Cyndon dactylon	Bermudagrass	■	■	■	■	■	■	■	■	■	■	■	■
Dicanthium annualatum	Kleberg Bluestem							■					
Eustachys retusa	Argentine Fingergrass	■						■	■		■	■	
Paspalum notatum	Bahiagrass	■	■	■		■	■	■	■	■	■	■	
Sorgum halapense	Johnsongrass		■	■		■	■	■	■	■	■	■	■
Forbs - Native													
Ambrosia artemisiifolia	Common Ragweed	■	■	■		■				■		■	■
Ambrosia trifida	Giant Ragweed			■									
Castilleja indivisa	Indian Paintbrush		■			■	■		■	■		■	■
Coreopsis tinctoria	Plains Coreopsis	■						■	■	■		■	■
Croton glandulosus	Tropic Croton	■	■		■		■		■	■	■		■
Gaillardia pulchella	Indian Blanket						■						
Geranium carolinianum	Crane’s Bill	■	■	■	■	■	■	■	■	■	■	■	■
Lepidium austrinum	Pepperweed		■							■			■
Lupinus texensis	Bluebonnet						■		■		■		
Monarda citridora	Horsemint	■	■	■	■	■	■	■	■	■	■	■	■
Plantago patagonica	Bristle-brach Plantain		■	■		■		■	■	■	■		
Polytaenia nuttallii	Prairie Parsley	■		■									
Ptilimnium capillaceum	Mock Bishop Weed					■		■	■				
Rudbeckia hirta	Coneflower	■	■	■	■	■	■	■	■	■	■	■	
Valerianella woodsiana	Woods Corn Salad	■		■				■			■		
Allium canadense	Meadow Garlic					■				■			
Asclepias viridis	Green Milkweed	■		■	■	■	■		■	■		■	
Baptisia bracteata	Plains Wild Indigo									■			
Callirhoe involuucrata	Wine Cup	■	■	■	■	■	■	■	■	■	■	■	■
Campsis radicans	Trumpet Vine												■
Cirsium texanum	Texas Thistle	■	■	■	■	■	■	■	■	■	■	■	■
Cocculus carolinus	Snailseed				■								■
Commelina erecta	Erect Dayflower	■				■							■

Desmanthus illinoensis	Illinois Bundleflower					■	■		■	■	■	■	
Dichondra carolinianus	Dichondra	■									■	■	
Erigeron philadelphicus	Fleabane										■	■	
Lespedeza virginica	Slender Bush-clover									■			
Lippia nodiflora	Frog Fruit	■								■			
Mimosa nuttallii	Catclaw Sensitive-briar	■	■			■			■				
Oenathera speciosa	Showey Primrose	■	■	■	■	■	■	■	■	■	■	■	■
Opuntia engelmannia	Prickly Pear Cactus										■		
Passiflora incarnata	Passionvine								■			■	
Penstemon cobaea	Foxglove									■			
Ratibida columnaris	Mexican Hat										■	■	
Rubus trivalis	Dewberry			■	■								
Solanum elaeagnifolum	Nightshade	■	■		■	■	■						■
Spiranthes lacera	Slender Ladies-tresses					■	■						
Tragia ramosa	Noseburn	■											■
Verbena halei	Texas Vervain	■	■	■	■	■	■	■	■	■	■	■	■
Forbs – Introduced													
Anagallis arvensis	Scarlet Pimpernell							■			■		
Arenaria serpyllifolia	Thymeleaf Sandwort												
Bellardia trixago	Germander						■			■		■	
Brassica juncea	Chinese Mustard												■
Lathyrus hirsutus	Singletary Pea		■	■	■	■	■		■	■		■	
Medicago arabica	Spotted Bur Clover		■	■	■	■	■	■	■			■	■
Melilotus officinalis	Yellow Sweet Clover			■	■	■	■	■		■	■	■	■
Trifolium vesiculosum	Arrow-leaf Clover											■	
Vicia villosa	Winter Vetch	■		■		■					■		
Rumex crispus	Curly Dock									■			■
Trees/Shrubs													
Acacia smallii	Huisache				■	■				■	■		
Bumelia lanuginosa	Gum Bumelia		■					■					
Prosopis glanulosa	Mesquite		■										
Ulmus alata	Winged Elm		■						■		■		

SB : South Bound
NB : North Bound

APPENDIX C. COVER PERCENTAGE OF DOMINANT GRASSES ON EXISTING AND NEW PLOTS

Appendix C.1. Cover Percentage of Dominant Grasses on Existing Plots

Graminoid Species				12/02/ 2004	11/15/ 2005	06/29/ 2006		12/05/2006		07/13/2007	
Academic Name	Common Name	US Nativity	Height			Mowed (M)	Unmowed (UM)	M	UM	M	UM
3:1 Sand Crownvetch											
Andropogon virginicus	Broomsedge Bluestem	N	T	II	II	-	II	-	II	I	I
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	-	-	-	I	-
Panicum capillare	Witchgrass	N	S	I	I	-	I	-	I	-	-
Panicum virgatum	Switchgrass	N	T	I	I	-	I	-	I	I	I
Schizachyrium scoparium	Little Bluestem	N	T	I	I	I	I	I	I	I	I
Sorghastrum nutans	Indiangrass	N	T	I	I	I	I	I	I	I	II
Bromus japonicus	Japanese Brome	IN	T	-	-	-	-	-	-	I	I
Cynodon dactylon	Bermudagrass	IN	S	I	I	-	I	-	I	-	-
Dicanthium annualatum	Kleberg Bluestem	IN	T	VI	VI	VI	V	VI	V	V	V
Sorghum halepense	Johnsongrass	IN	T	I	I	-	I	-	I	-	I
3:1 Sand Native Forbs and Grasses											
Andropogon virginicus	Broomsedge Bluestem	N	T	II	II	I	I	I	I	II	II
Bouteloua curtipendula	Sideoats Grama	N	S	III	III	II	I	II	I	II	I
Panicum virgatum	Switchgrass	N	T	II	II	II	II	II	II	I	I
Schizachyrium scoparium	Little Bluestem	N	T	II	II	II	II	II	II	I	I
Sorghastrum nutans	Indiangrass	N	T	I	I	I	I	I	I	I	I
Bromus japonicus	Japanese Brome	IN	T	-	-	-	-	-	-	I	-
Dicanthium annualatum	Kleberg Bluestem	IN	T	V	V	V	V	V	V	V	V
Sorghum halepense	Johnsongrass	IN	T	I	I	I	I	I	I	I	I
3:1 Sand Wildflower Mix											
Andropogon virginicus	Broomsedge Bluestem	N	T	II	II	I	I	I	I	I	II
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	-	-	-	I	I
Panicum virgatum	Switchgrass	N	T	II	II	II	II	II	II	I	II
Schizachyrium scoparium	Little Bluestem	N	T	-	-	-	-	-	-	I	I
Bothriochloa ischaemum	K.R. Bluestem	IN	S	-	-	-	-	-	-	I	II
Dicanthium annualatum	Kleberg Bluestem	IN	T	V	V	VI	V	VI	V	V	V
3:1 Sand Native Grasses											
Bouteloua curtipendula	Sideoats Grama	N	S	III	III	III	II	III	II	II	II
Panicum virgatum	Switchgrass	N	T	VI	VI	III	V	III	V	II	VI
Schizachyrium scoparium	Little Bluestem	N	T	I	II	I	I	I	I	I	I
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	-	IV	I

3:1 Sand Controls											
Andropogon virginicus	Broomsedge Bluestem	N	T	I	III	I	III	I	III	I	III
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	-	-	-	I	I
Panicum virgatum	Switchgrass	N	T	I	I	I	I	-	I	I	III
Sorghastrum nutans	Indiangrass	N	T	I	-	-	-	-	-	I	-
Bothriochloa ischaemum	K.R. Bluestem	IN	S	-	-	-	-	-	-	I	I
Bromus japonicus	Japanese Brome	IN	T	-	-	-	-	-	-	I	-
Cynodon dactylon	Bermudagrass	IN	S	I	-	-	-	-	-	-	-
Dicanthium annualatum	Kleberg Bluestem	IN	T	VI	VI	VI	VI	VI	VI	V	IV
2:1 Clay Crownvetch											
Bothriochloa laguroides	Silver Bluestem	N	T	II	II	II	II	II	II	II	IV
Bouteloua curtipendula	Sideoats Grama	N	S	II	II	II	II	II	II	-	-
Panicum capillare	Witchgrass	N	S	I	I	I	I	I	I	-	-
Panicum virgatum	Switchgrass	N	T	II	II	II	II	I	II	I	II
Bothriochloa ischaemum	K.R. Bluestem	IN	S	I	I	I	I	I	I	II	-
Dicanthium annualatum	Kleberg Bluestem	IN	T	I	I	II	II	III	II	-	-
Sorghum halepense	Johnsongrass	IN	T	-	-	-	-	-	-	I	I
2:1 Clay Native Forbs and Grasses											
Bothriochloa laguroides	Silver Bluestem	N	T	I	I	I	I	II	I	I	-
Bouteloua curtipendula	Sideoats Grama	N	S	I	I	I	I	II	I	III	III
Panicum virgatum	Switchgrass	N	T	V	V	VI	V	II	V	III	V
Sorghum halepense	Johnsongrass	IN	T	I	I	I	I	I	I	-	-
2:1 Clay Wildflower Mix											
Bothriochloa laguroides	Silver Bluestem	N	T	I	I	II	II	II	II	II	I
Bouteloua curtipendula	Sideoats Grama	N	S	I	II	II	II	II	II	III	V
Panicum capillare	Witchgrass	N	S	I	I	I	I	I	I	-	-
Panicum virgatum	Switchgrass	N	T	I	I	I	I	I	I	I	-
Dicanthium annualatum	Kleberg Bluestem	IN	T	I	I	I	I	I	I	-	-
Sorghum halepense	Johnsongrass	IN	T	II	II	I	I	I	I	-	-
2:1 Clay Native Grasses											
Bothriochloa laguroides	Silver Bluestem	N	T	I	I	I	I	I	I	III	III
Bouteloua curtipendula	Sideoats Grama	N	S	II	V	V	V	V	V	V	II
Dicanthium annualatum	Kleberg Bluestem	IN	T	II	II	II	II	II	II	-	-
Sorghum halepense	Johnsongrass	IN	T	II	II	II	II	II	II	-	-
2:1 Clay Controls											
Bothriochloa laguroides	Silver Bluestem	N	T	I	I	II	II	I	III	III	I
Bouteloua curtipendula	Sideoats Grama	N	S	I	II	I	I	II	I	I	I
Dichanthelium oligosanthes	Scribner Dichanthelium	N	S	-	-	-	-	-	-	I	I
Panicum capillare	Witchgrass	N	S	I	I	I	I	I	I	-	-
Bothriochloa ischaemum	K.R. Bluestem	IN	S	I	I	II	II	II	II	I	I

orghum halepense	Johnsongrass	IN	T	III	III	I	I	I	I	I	I

M: Mowed, UM: Unmowed
N: Native, IN: Introduced
T: Tallgrass, S: Shortgrass
I = 0-5%, II = 6-20%, III = 21-50%, IV = 51-80%, V = 81-95%, VI = 95-100%

Appendix C.2. Cover Percentage of Dominant Grasses on New Plots

Graminoid Species				**11/15/2005**	**6/29/2006**		**12/5/2006**		**7/13/2007**	
Academic Name	**Common Name**	**US Nativity**	**Height**		**Mowed (M)**	**Unmowed (UM)**	**M**	**UM**	**M**	**UM**
New Sand 1										
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	I	I	I	I
Schizachyrium scoparium	Little Bluestem	N	T	-	-	-	-	-	I	I
Cynodon dactylon	Bermuda	IN	S	I	I	I	I	I	I	I
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	I	I
Eragrostis curvula	Weeping Lovegrass	IN	T	IV	IV	IV	IV	IV	IV	IV
Paspalum notatum	Bahiagrass	IN	S	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	I	I	I	II	I	I	I
Bare Ground				0%	80%	80%	60%	60%	0%	0%
New Sand 2										
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	I	I	I	I
Chloris sp.	Chloris sp.			I	-	-	-	-	-	-
Schizachyrium scoparium	Little Bluestem	N	T	-	-	-	-	-	I	I
Cynodon dactylon	Bermuda	IN	S	I	I	I	I	I	I	I
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	I	I
Eragrostis curvula	Weeping Lovegrass	IN	T	IV	IV	IV	IV	IV	IV	IV
Paspalum notatum	Bahiagrass	IN	S	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	I	I	I	I	I	I	I
Bare Ground				0	0.8	0.8	0.6	0.5	0	0
New Sand 3										
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	I	I	I	I
Chloris sp.	Chloris sp.			I	-	-	-	-	-	-
Schizachyrium scoparium	Little Bluestem	N	T	-	-	-	-	-	I	I
Cynodon dactylon	Bermuda	IN	S	I	I	I	I	I	I	I
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	I	I
Eragrostis curvula	Weeping Lovegrass	IN	T	V	V	V	V	V	IV	IV
Paspalum notatum	Bahiagrass	IN	S	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	I	I	I	I	II	I	I
Bare Ground				0%	80%	80%	60%	60%	0%	0%
New Sand 4										
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	I	I	I	I
Chloris sp.	Chloris sp.			I	-	-	-	-	-	-
Leptochloa dubia	Sprangletop	N	S	I	-	-	-	-	-	-
Schizachyrium	Little Bluestem	N	T	-	-	-	-	-	I	I

scoparium										
Cynodon dactylon	Bermuda	IN	S	I	II	II	II	II	I	I
Cyperus rotundus	Nutsedge	IN	S	III	I	I	I	I	-	-
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	I	I
Eragrostis curvula	Weeping Lovegrass	IN	T	IV	IV	IV	IV	IV	IV	IV
Paspalum notatum	Bahiagrass	IN	S	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	II	II	II	II	II	I	I
Bare Ground				0%	80%	80%	50%	50%	0%	0%
New Sand 5										
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	I	I	I	I
Chloris sp.	Chloris sp.			I	-	-	-	-	-	-
Leptochloa dubia	Sprangletop	N	S	I	-	-	-	-	-	-
Panicum virgatum	Switchgrass	N	T	I	-	-	-	-	-	-
Schizachyrium scoparium	Little Bluestem	N	T	-	-	-	-	-	I	I
Cynodon dactylon	Bermuda	IN	S	I	I	I	I	I	I	I
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	I	I
Eragrostis curvula	Weeping Lovegrass	IN	T	IV	IV	IV	IV	IV	IV	IV
Paspalum notatum	Bahiagrass	IN	S	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	I	II	II	II	II	I	I
Bare Ground				0%	80%	80%	80%	80%	0%	0%
New Sand 6										
Bouteloua curtipendula	Sideoats Grama	N	S	-	-	-	I	I	I	I
Chloris sp.	Chloris sp.			I	-	-	-	-	-	-
Leptochloa dubia	Sprangletop	N	S	I	-	-	-	-	-	-
Panicum virgatum	Switchgrass	N	T	I	-	-	-	-	-	-
Schizachyrium scoparium	Little Bluestem	N	T	-	-	-	-	-	I	I
Cynodon dactylon	Bermuda	IN	S	I	I	I	I	I	I	I
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	I	I
Eragrostis curvula	Weeping Lovegrass	IN	T	V	V	V	V	V	IV	IV
Paspalum notatum	Bahiagrass	IN	S	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	I	I	I	II	II	I	I
Bare Ground				0%	80%	80%	50%	50%	0%	0%
New Clay 1										
Bouteloua curtipendula	Sideoats Grama	N	S	I	I	I	III	III	V	V
Panicum virgatum	Switchgrass	N	T	-	-	-	-	-	-	I
Sorghastrum nutans	Indiangrass	N	T	-	-	-	-	-	-	I
Bothriochloa ischaemum	K.R. Bluestem	IN	S	I	I	I	I	I	-	-
Sorghum halepense	Johnsongrass	IN	T	V	V	V	V	V	IV	II
Bare Ground				0%	40%	40%	40%	40%	0%	0%
New Clay 2										
Bouteloua curtipendula	Sideoats Grama	N	S	I	I	I	III	III	IV	IV
Panicum virgatum	Switchgrass	N	T	I	I	I	I	I	-	I
Sorghastrum nutans	Indiangrass	N	T	-	-	-	-	-	I	-
Bothriochloa ischaemum	K.R. Bluestem	IN	S	-	-	-	-	-	I	-

Sorghum halepense	Johnsongrass	IN	T	V	V	V	V	V	IV	IV
Bare Ground				0%	30%	30%	30%	20%	0%	0%
New Clay 3										
Bouteloua curtipendula	Sideoats Grama	N	S	II	II	II	III	III	IV	IV
Panicum virgatum	Switchgrass	N	T	I	I	I	I	I	-	-
Sorghastrum nutans	Indiangrass	N	T	-	-	-	-	-	I	I
Bothriochloa ischaemum	K.R. Bluestem	IN	S	I	I	I	I	I	-	-
Cynodon dactylon	Bermuda	IN	S	I	I	I	I	I	-	-
Sorghum halepense	Johnsongrass	IN	T	V	V	V	V	V	III	III
Bare Ground				0%	10%	10%	10%	5%	0%	0%
New Clay 4										
Bouteloua curtipendula	Sideoats Grama	N	S	III	II	II	II	II	IV	IV
Panicum virgatum	Switchgrass	N	T	I	I	I	I	I	I	I
Sorghastrum nutans	Indiangrass	N	T	I	I	I	I	I	I	I
Dicanthium annualatum	Kleberg Bluestem	IN	T	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	VI	VI	VI	VI	VI	III	III
Bare Ground				0%	20%	20%	10%	10%		
New Clay 5										
Bouteloua curtipendula	Sideoats Grama	N	S	III	I	-	I	IV	I	III
Panicum virgatum	Switchgrass	N	T	III	II	VI	II	VI	II	VI
Sorghastrum nutans	Indiangrass	N	T	II	I	I	I	I	II	I
Bothriochloa ischaemum	K.R. Bluestem	IN	S	-	-	-	-	-	I	I
Sorghum halepense	Johnsongrass	IN	T	V	V	I	V	I	III	I
Bare Ground				0%	10%	10%	10%	0%	0%	0%
New Clay 6										
Bouteloua curtipendula	Sideoats Grama	N	S	III	III	III	III	III	III	IV
Panicum virgatum	Switchgrass	N	T	IV	IV	IV	IV	IV	I	I
Sorghastrum nutans	Indiangrass	N	T	III	III	III	III	III	I	I
Bothriochloa ischaemum	K.R. Bluestem	IN	S	I	I	I	I	I	-	-
Sorghum halepense	Johnsongrass	IN	T	II	II	II	II	III	II	III
Bare Ground				0%	30%	30%	30%	10%	0%	0%

M: Mowed, UM: Unmowed
N: Native, IN: Introduced
T: Tallgrass, S: Shortgrass
I = 0-5%, II = 6-20%, III = 21-50%, IV = 51-80%, V = 81-95%, VI = 95-100%

APPENDIX D. OBSERVED VEGETATION SPECIES ON EXISTING AND NEW PLOTS DURING 07/17/2007 SURVEY

Appendix D.1. Observed Vegetation Species on Existing Plots During 07/17/2007 Survey

Botanical name	Common name	Crownvetch		Native Forbs and Grasses		Wildflower Mix Sand		Native Grasses		Control	
		M	UM	M	UM	M	UM	M	UM	M	UM
Native Grasses											
Andropogon virginicus	Bushy Broomsedge	I	I	II	II	I	II			I	III
Bouteloua curtipendula	Sideoats Grama	I		II	I	I	I	II	II	I	I
Panicum virgatum	Switchgrass	I	I	I	I	I	II	II	VI	I	III
Schizachyrium scoparium	Little Bluestem	I	I	I	I	I	I	I	I		
Sorghastrum nutans	Indiangrass	I	II	I	II					I	
Non-native Grasses											
Bothriochloa ischaemum	K.R. Bluestem					I	II			I	I
Bromus japonicus	Japanese Brome	I	I	I						I	
Dicanthium annualatum	Kleberg Bluestem	V	V	V	V	V	V	IV	I	V	IV
Sorgum halapense	Johnsongrass		I	I	I						
Forbs											
Ambrosia artemisiifolia	Common Ragweed	II	I			I	I			I	I
Cassia fasciculata	Partridge Pea			I	I						
Commelina erecta	Erect Dayflower				I						
Croton glandulosus	Tropic Croton	II	I	I	I					I	I
Desmanthus illinoensis	Illinois Bundleflower			I	I	I	I				
Helianthus annuus	Common Sunflower	I	I	I	I	I	I	I	I	I	II
Ipomoea sp.	Morning Glory	I	I	I	I	I	I	I	I	I	II
Lepidium austrinum	Pepperweed			I		I	I				I
Lespedeza virginica	Slender Bush Clover			I							
Monarda citridora	Horsemint					I	I			I	I
Polytaenia nuttallii	Prairie Parsley			I			I		I	I	I
Ratibida columnaris	Mexican Hat	I	I	I	I			I		I	
Rubus trivalis	Dewberry										I
Schrankia uncinata	Sensitive Briar			I		I	I	I	I	I	III
Sebania sp.	Rattlebush	I	I			I	I		I	IV	I
Verbena halei	Texas Vervain		I	I	I			I			
	Bare Ground	I			I	I		I		II	
	Plant Litter		I	I		II	I	II	I	I	III

Botanical name	Common name	Clay Plot 1		Clay Plot 2		Clay Plot 3		Clay Plot 4		Clay Plot 5	
		M	UM	M	UM	M	UM	M	UM	M	UM
Native Grasses											
Bouteloua curtipendula	Sideoats Grama	I	I	V	V	IV	IV	IV	IV	IV	IV
Eragrostis curvula	Weeping Lovegrass	IV	IV								
Panicum virgatum	Switchgrass				I		I			I	I
Schizachyrium scoparium	Little Bluestem	I	I								
Sorghastrum nutans	Indiangrass				I	I		I	I	I	I
Non-native Grasses											
Bothriochloa ischaemum	K.R. Bluestem					I					

Cyndon dactylon	Bermudagrass	I	I								
Dicanthium annualatum	Kleberg Bluestem	I	I							I	I
Paspalum notatum	Bahiagrass	I	I								
Sorgum halapense	Johnsongrass	I	I	IV	II	IV	IV	III	III	III	III
Forbs											
Ambrosia trifida	Giant Ragweed			II	I						
Coreopsis tinctoria	Plains Coreopsis	I	I								
Croton glandulosus	Tropic Croton	I	I	I	I	I	I			I	I
Desmanthus illinoensis	Illinois Bundleflower			I	I	I	I	I	I	I	I
Helianthus annuus	Common Sunflower	I								I	I
Ipomoea sp.	Morning Glory							I	I		
Monarda citridora	Horsemint	I	I	I	I	I	I			I	I
Plantago patagonica	Bristle-brach Plantain			I	I	I	I				
Schrankia uncinata	Sensitive Briar	I	I	II	II	II	II	I	I	II	II
Sebania sp.	Rattlebush	IV	IV	II	I	II	III	II	II	II	II
Verbena halei	Texas Vervain				I					I	I
Unidentified Forb 1								I	I	I	I
Unidentified Forb 2								I	I		
	Bare Ground	IV	IV			II	I	I	I		
	Plant Litter						I	I	I	II	II

Appendix D.2. Observed Vegetation Species on New Plots during 07/17/2007 Survey

Botanical name	Common name	Sand Plots		Clay Plot 1		Clay Plot 2		Clay Plot 3		Clay Plot 4		Clay Plot 5		Clay Plot 6	
		M	**UM**	**M**	**UM**	**M**	**UM**	**M**	**UM**	**M**	**UM**	**M**	**UM**	**M**	**UM**
Native Grasses															
Bouteloua curtipendula	Sideoats Grama	I	I	V	V	IV	IV	IV	IV	IV	IV	I	III	III	IV
Eragrostis curvula	Weeping Lovegrass	IV	IV												
Panicum virgatum	Switchgrass				I		I			I	I	II	VI	I	I
Schizachyrium scoparium	Little Bluestem	I	I												
Sorghastrum nutans	Indiangrass				I	I		I	I	I	I	II	I	I	I
Non-native Grasses															
Bothriochloa ischaemum	K.R. Bluestem					I						I	I		
Cyndon dactylon	Bermudagrass	I	I												
Dicanthium annualatum	Kleberg Bluestem	I	I							I	I				
Paspalum notatum	Bahiagrass	I	I												
Sorgum halapense	Johnsongrass	I	I	IV	II	IV	IV	III	III	III	III	III	I	II	III
Forbs															
Ambrosia trifida	Giant Ragweed			II	I										
Coreopsis tinctoria	Plains Coreopsis	I	I												
Croton glandulosus	Tropic Croton	I	I	I	I	I	I			I	I				I
Desmanthus illinoensis	Illinois Bundleflower			I	I	I	I	I	I	I	I	I	I	II	I
Helianthus annuus	Common Sunflower	I								I	I	I	I	I	I
Ipomoea sp.	Morning Glory							I	I						
Monarda citridora	Horsemint	I	I	I	I	I	I			I	I			I	I
Plantago patagonica	Bristle-brach Plantain			I	I	I	I							I	I
Schrankia uncinata	Sensitive Briar	I	I	II	II	II	II	I	I	II	II	I	I		
Sebania sp.	Rattlebush	IV	IV	II	I	II	III	II	II	II	II	I	I	I	II
Verbena halei	Texas Vervain				I					I	I				
Unidentified Forb 1								I	I	I	I	I	I	I	I
Unidentified Forb 2								I	I						
	Bare Ground	IV	IV			II	I	I	I			II		II	
	Plant Litter						I	I	I	II	II	I	II		II

M: Mowed, UM: Unmowed

I = 0-5%, II = 6-20%, III = 21-50%, IV = 51-80%, V = 81-95%, VI = 95-100%

APPENDIX E. SPECIES COMPARISON BETWEEN THE SEEDED AND OBSERVED (IN 2007) VEGETATION SPECIES ON EXISTING PLOTS

Appendix E.1. Species Comparison between the Seeded and Observed (in 2007) Vegetation Species on Existing Crownvetch Plots

Seed mix			2007					
			Mowed			Unmowed		
Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity
Forbs			**Grasses**			**Grasses**		
Securigera varia	Crownvetch	IN	*Andropogon virginicus*	Broomsedge Bluestem	N	*Andropogon virginicus*	Broomsedge Bluestem	N
			Bouteloua curtipendula	Sideoats Grama	N	*Panicum virgatum*	Switchgrass	N
			Panicum virgatum	Switchgrass	N	*Schizachyrium scoparium*	Little Bluestem	N
			Schizachyrium scoparium	Little Bluestem	N	*Sorghastrum nutans*	Indiangrass	N
			Sorghastrum nutans	Indiangrass	N	*Bromus japonicus*	Japanese Brome	IN
			Bromus japonicus	Japanese Brome	IN	*Dicanthium annualatum*	Kleberg Bluestem	IN
			Dicanthium annualatum	Kleberg Bluestem	IN	*Sorgum halapense*	Johnsongrass	IN
			Forbs			**Forbs**		
			Ambrosia artemisiifolia	Common Ragweed	N	*Ambrosia artemisiifolia*	Common Ragweed	N
			Ambrosia trifida	Giant Ragweed	N	*Ambrosia trifida*	Giant Ragweed	N
			Croton glandulosus	Tropic Croton	N	*Croton glandulosus*	Tropic Croton	N
			Helianthus annuus	Common Sunflower	N	*Helianthus annuus*	Common Sunflower	N
			Monarda citridora	Lemon Mint	N	*Lepidium austrinum*	Pepperweed	N
			Rubus trivalis	Dewberry	N	*Monarda citridora*	Lemon Mint	N
			Ratibida columnaris	Mexican Hat	N	*Rubus trivalis*	Dewberry	N
			Schrankia uncinata	Sensitive Briar	N	*Schrankia uncinata*	Sensitive Briar	N
			Ipomoea sp.	Morning Glory	IN	*Ratibida columnaris*	Mexican Hat	N
			Sebania sp.	Rattlebush	IN	*Verbena halei*	Texas Vervain	N
						Ipomoea sp.	Morning Glory	IN
						Sebania sp.	Rattlebush	IN

N: Native, IN: Introduced
* Seeded species occurring in 2007

Appendix E.2. Species Comparison between the Seeded and Observed (in 2007) Vegetation Species on Existing Native Forbs and Grasses Plots

Seed mix			2007					
			Mowed			Unmowed		
Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity
Grasses			**Grasses**			**Grasses**		
Bouteloua curtipendula	Sideoats Grama	N	*Andropogon virginicus*	Broomsedge Bluestem	N	*Andropogon virginicus*	Broomsedge Bluestem	N
Elymus canadensis	Canada Wildrye	N	*Bothriochloa laguroides*	Silver Bluestem	N	*Bouteloua curtipendula**	Sideoats Grama	N
Schizachyrium scoparium	Little Bluestem	N	*Bouteloua curtipendula**	Sideoats Grama	N	*Panicum virgatum*	Switchgrass	N
Sorghastrum nutans	Indiangrass	N	*Panicum virgatum*	Switchgrass	N	*Schizachyrium scoparium**	Little Bluestem	N
			*Schizachyrium scoparium**	Little Bluestem	N	*Sorghastrum nutans**	Indiangrass	N
			*Sorghastrum nutans**	Indiangrass	N	*Dicanthium annualatum*	Kleberg Bluestem	IN
			Bromus japonicus	Japanese Brome	IN	*Sorgum halapense*	Johnsongrass	IN
			Dicanthium annualatum	Kleberg Bluestem	IN			
			Sorgum halapense	Johnsongrass	IN			
Forbs			**Forbs**			**Forbs**		
Asclepias L.	Milkweed	N	*Ambrosia trifida*	Giant Ragweed	N			
Callirhoe involucrata	Wine Cup	N	*Cassia fasciculata*	Partridge Pea	N	*Cassia fasciculata*	Partridge Pea	N
Castilleja spp.	Indian Paintbrush	N	*Croton glandulosus*	Tropic Croton	N	*Commelina erecta*	Erect Dayflower	N
Coreopsis tinctoria	Plains Coreopsis	N	*Desmanthus illinoensis*	Illinois Bundleflower	N	*Croton glandulosus*	Tropic Croton	N
Gaillardia aristata	Blanket Flower	N	*Helianthus annuus*	Common Sunflower	N	*Desmanthus illinoensis*	Illinois Bundleflower	N
Helianthus maximiliani	Maximilian Sunflower	N	*Lepidium austrinum*	Pepperweed	N	*Helianthus annuus*	Common Sunflower	N
Liatris mucronata	Gayfeather	N	*Lespedeza virginica*	Slender Bush Clover	N	*Monarda citridora*	Lemon Mint	N
Lupinus texensis	Texas Lupine	N	*Monarda citridora*	Lemon Mint	N	*Ratibida columnaris*	Mexican Hat	N
Machaeranthera tanacetifolia	Prairie Aster	N	*Polytaenia nuttallii*	Prairie Parsley	N	*Verbena halei*	Texas Vervain	N
Monarda spp.	Bergamot	N	*Ratibida columnaris*	Mexican Hat	N	*Ipomoea* sp.	Morning Glory	IN
Oenothera hookeri.	Yellow Evening Primrose	N	*Schrankia uncinata*	Sensitive Briar	N			
Penstemon strictus	Rocky Mountain Penstemon	N	*Verbena halei*	Texas Vervain	N			
Petalostemum purpureum	Purple Prairie Clover	N	*Ipomoea* sp.	Morning Glory	IN			
Rudbeckia hirta	Black-eyed Susan	N						
Salvia farinacea	Mealy Blue Sage	N						

N: Native, IN: Introduced
* Seeded species occurring in 2007

Appendix E.3. Species Comparison between the Seeded and Observed (in 2007) Vegetation Species on Existing Wildflower Mix Plots

Seed mix			2007					
			Mowed			Unmowed		
Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity
Forbs			**Grasses**			**Grasses**		
Achillea millefolium	Yarrow	N	*Andropogon virginicus*	Broomsedge Bluestem	N	*Andropogon virginicus*	Broomsedge Bluestem	N
Castilleja indivisa	Texas Paintbrush	N	*Bothriochloa laguroides*	Silver Bluestem	N	*Bothriochloa laguroides*	Silver Bluestem	N
Coreopsis lanceolata	Lanceleaf Tickseed	N	*Bouteloua curtipendula*	Sideoats Grama	N	*Bouteloua curtipendula*	Sideoats Grama	N
Coreopsis tinctoria	Plains Coreopsis	N	*Panicum virgatum*	Switchgrass	N	*Panicum virgatum*	Switchgrass	N
Coreopsis tinctoria, dwarf red	Dwarf Red Coreopsis	N	*Schizachyrium scoparium*	Little Bluestem	N	*Schizachyrium scoparium*	Little Bluestem	N
Echinacea purpurea	Purple Coneflower	N	*Bothriochloa ischaemum*	K.R. Bluestem	IN	*Bothriochloa ischaemum*	K.R. Bluestem	IN
Eschscholzia californica	California Poppy	N	*Dicanthium annualatum*	Kleberg Bluestem	IN	*Dicanthium annualatum*	Kleberg Bluestem	IN
Gaillardia pulchella	Indian Blanket	N	**Forbs**			**Forbs**		
Lupinus subcarnosus	Texas Bluebonnet	N	*Ambrosia artemisiifolia*	Common Ragweed	N	*Ambrosia artemisiifolia*	Common Ragweed	N
Monarda citriodora	Lemon Mint	N	*Croton glandulosus*	Tropic Croton	N	*Croton glandulosus*	Tropic Croton	N
Nemophila insignis	Baby Blue-eyes	N	*Desmanthus illinoensis*	Illinois Bundleflower	N	*Desmanthus illinoensis*	Illinois Bundleflower	N
Oenothera speciosa	Showy Primrose	N	*Helianthus annuus*	Common Sunflower	N	*Helianthus annuus*	Common Sunflower	N
Phlox drummondii	Drummond Phlox	N	*Lepidium austrinum*	Pepperweed	N	*Lepidium austrinum*	Pepperweed	N
Ratibida columnaris	Mexican Hat	N	*Monarda citridora**	Lemon Mint	N	*Monarda citridora**	Lemon Mint	N
Rudbeckia amplexicaulis	Clasping Coneflower	N	*Plantago patagonica*	Bristle-brach Plantain	N	*Plantago patagonica*	Bristle-brach Plantain	N
Rudbeckia hirta	Black-eyed Susan	N	*Rubus trivalis*	Dewberry	N	*Polytaenia nuttallii*	Prairie Parsley	N
Centaurea cyanus	Cornflower	IN	*Schrankia uncinata*	Sensitive Briar	N	*Rubus trivalis*	Dewberry	N
Chrysanthemum leucanthemum	Ox-eye Daisy	IN	*Sebania* sp.	Rattlebush	IN	*Schrankia uncinata*	Sensitive Briar	N
Cosmos sulphureus	Yellow Cosmos	IN	*Verbena halei*	Texas Vervain	N	*Sebania* sp.	Rattlebush	IN
Delphinium ajacis	Rocket Larkspur	IN	*Ipomoea* sp.	Morning Glory	IN	*Verbena halei*	Texas Vervain	N
Gypsophila muralis	Baby's Breath	IN				*Ipomoea* sp.	Morning Glory	IN
Linaria maroccana	Toadflax	IN				*Rosa* sp.	Wild Rose	
Linum rubrum	Scarlet Flax	IN						
Papaver rhoeas	Corn Poppy	IN						
Verbena rigida	Tuber Vervain	IN						

N: Native, IN: Introduced
* Seeded species occurring in 2007

Appendix E.4. Species Comparison between the Seeded and Observed (in 2007) Vegetation Species on Existing Native Grasses Plots

Seed mix			2007					
			Mowed			Unmowed		
Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity
Grasses			**Grasses**			**Grasses**		
Bouteloua curtipendula	Sideoats Grama	N	*Bothriochloa laguroides*	Silver Bluestem	N	*Bothriochloa laguroides*	Silver Bluestem	N
Elymus canadensis	Canada Wildrye	N	*Bouteloua curtipendula**	Sideoats Grama	N	*Bouteloua curtipendula**	Sideoats Grama	N
Koeleria macrantha	June Grass	N	*Panicum virgatum*	Switchgrass	N	*Panicum virgatum*	Switchgrass	N
Panicum virgatum	Switchgrass	N	*Schizachyrium scoparium**	Little Bluestem	N	*Schizachyrium scoparium**	Little Bluestem	N
Schizachyrium scoparium	Little Bluestem	N	*Sorghastrum nutans**	Indiangrass	N	*Sorghastrum nutans**	Indiangrass	N
Sorghastrum nutans	Indiangrass	N	*Dicanthium annualatum*	Kleberg Bluestem	IN	*Dicanthium annualatum*	Kleberg Bluestem	IN
Sporobolus heterolepis	Prairie Drop Seed	N	**Forbs**			**Forbs**		
			Ambrosia trifida	Giant Ragweed	N	*Ambrosia trifida*	Giant Ragweed	N
			Croton glandulosus	Tropic Croton	N	*Croton glandulosus*	Tropic Croton	N
			Desmanthus illinoensis	Illinois Bundleflower	N	*Helianthus annuus*	Common Sunflower	N
			Helianthus annuus	Common Sunflower	N	*Monarda citridora*	Lemon Mint	N
			Monarda citridora	Lemon Mint	N	*Polytaenia nuttallii*	Prairie Parsley	N
			Ratibida columnaris	Mexican Hat	N	*Salvia farinacea*	Blue Salvia	N
			Rubus trivalis	Dewberry	N	*Schrankia uncinata*	Sensitive Briar	N
			Salvia farinacea	Blue Salvia	N	*Verbena halei*	Texas Vervain	N
			Schrankia uncinata	Sensitive Briar	N	*Ipomoea* sp.	Morning Glory	IN
			Verbena halei	Texas Vervain	N	*Sebania* sp.	Rattlebush	IN
			Ipomoea sp.	Morning Glory	IN	Unidentified Forb		

N: Native, IN: Introduced
* Seeded species occurring in 2007

Appendix E.5. Species Comparison between the Seeded and Observed (in 2007) Vegetation Species on Existing Control (Bemudagrass only) Plots

Seed mix			2007					
			Mowed			Unmowed		
Botanical Name	**Common Name**	**U.S. Nativity**	**Botanical Name**	**Common Name**	**U.S. Nativity**	**Botanical Name**	**Common Name**	**U.S. Nativity**
Grasses			**Grasses**			**Grasses**		
Cynodon dactylon	Bermudagrass	IN	*Andropogon virginicus*	Broomsedge Bluestem	N	*Andropogon virginicus*	Broomsedge Bluestem	N
			Bothriochloa laguroides	Silver Bluestem	N	*Bothriochloa laguroides*	Silver Bluestem	N
			Bouteloua curtipendula	Sideoats Grama	N	*Bouteloua curtipendula*	Sideoats Grama	N
			Dichanthelium oligosanthes	Scribner Dichanthelium	N	*Dichanthelium oligosanthes*	Scribner Dichanthelium	N
			Panicum virgatum	Switchgrass	N	*Panicum virgatum*	Switchgrass	N
			Sorghastrum nutans	Indiangrass	N	*Bothriochloa ischaemum*	K.R. Bluestem	IN
			Bothriochloa ischaemum	K.R. Bluestem	IN	*Dicanthium annualatum*	Kleberg Bluestem	IN
			Bromus japonicus	Japanese Brome	IN	*Sorgum halapense*	Johnsongrass	IN
			Dicanthium annualatum	Kleberg Bluestem	IN			
			Sorgum halapense	Johnsongrass	IN			
			Forbs			**Forbs**		
			Ambrosia artemisiifolia	Common Ragweed	N	*Ambrosia artemisiifolia*	Common Ragweed	N
			Croton glandulosus	Tropic Croton	N	*Croton glandulosus*	Tropic Croton	N
			Helianthus annuus	Common Sunflower	N	*Helianthus annuus*	Common Sunflower	N
			Monarda citridora	Lemon Mint	N	*Lepidium austrinum*	Pepperweed	N
			Plantago patagonica	Bristle-brach Plantain	N	*Monarda citridora*	Lemon Mint	N
			Polytaenia nuttallii	Prairie Parsley	N	*Plantago patagonica*	Bristle-brach Plantain	N
			Ratibida columnaris	Mexican Hat	N	*Polytaenia nuttallii*	Prairie Parsley	N
			Rubus trivalis	Dewberry	N	*Rubus trivalis*	Dewberry	N
			Salvia farinacea	Blue Salvia	N	*Salvia farinacea*	Blue Salvia	N
			Schrankia uncinata	Sensitive Briar	N	*Schrankia uncinata*	Sensitive Briar	N
			Verbena halei	Texas Vervain	N	*Verbena halei*	Texas Vervain	N
			Ipomoea sp.	Morning Glory	IN	*Ipomoea* sp.	Morning Glory	IN
			Sebania sp.	Rattlebush	IN	*Sebania* sp.	Rattlebush	IN
			Unidentified Forb			Unidentified Forb		

N: Native, IN: Introduced
* Seeded species occurring in 2007

Appendix E.6. Species Comparison between the Seeded and Observed (in 2007) Vegetation Species on New Sand Plots

Seed mix			2007					
			Mowed			Unmowed		
Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity
Grasses			**Grasses**			**Grasses**		
Eragrostis trichodes	Sand Lovegrass	N	*Bouteloua curtipendula*	Sideoats Grama	N	*Bouteloua curtipendula*	Sideoats Grama	N
Leptochloa dubia	Green Sprangletop	N	*Schizachyrium scoparium*	Little Bluestem	N	*Schizachyrium scoparium*	Little Bluestem	N
Cynodon dactylon	Bermudagrass	IN	*Cynodon dactylon**	Bermudagrass	IN	*Cynodon dactylon**	Bermudagrass	IN
Eragrostis curvula	Weeping Lovegrass	IN	*Eragrostis curvula**	Weeping Lovegrass	IN	*Eragrostis curvula**	Weeping Lovegrass	IN
Paspalum notatum	Bahiagrass	IN	*Dicanthium annualatum*	Kleberg Bluestem	IN	*Dicanthium annualatum*	Kleberg Bluestem	IN
			*Paspalum notatum**	Bahiagrass	IN	*Paspalum notatum**	Bahiagrass	IN
			Sorgum halapense	Johnsongrass	IN	*Sorgum halapense*	Johnsongrass	IN
Forbs			**Forbs**			**Forbs**		
Coreopsis lanceolata	Lance Leaf Coreopsis	N	*Coreopsis tinctoria*	Plains Coreopsis	N	*Coreopsis tinctoria*	Plains Coreopsis	N
			Croton glandulosus	Tropic Croton	N	*Croton glandulosus*	Tropic Croton	N
			Helianthus annuus	Common Sunflower	N	*Monarda citridora*	Lemon Mint	N
			Monarda citridora	Lemon Mint	N	*Schrankia uncinata*	Sensitive Briar	N
			Schrankia uncinata	Sensitive Briar	N	*Sebania* sp.	Rattlebush	IN
			Sebania sp.	Rattlebush	IN			

N: Native, IN: Introduced
* Seeded species occurring in 2007

Appendix E.7. Species Comparison Between the Seeded and Observed (in 2007) Vegetation Species on New Clay Plots

Seed mix			2007					
			Mowed			Unmowed		
Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity	Botanical Name	Common Name	U.S. Nativity
Grasses			**Grasses**			**Grasses**		
Bouleloua curtipendula	Sideoats Grama	N	*Bouteloua curtipendula**	Sideoats Grama	N	*Bouteloua curtipendula**	Sideoats Grama	N
Leptochloa dubia	Green Sprangletop	N	*Panicum virgatum*	Switchgrass	N	*Panicum virgatum*	Switchgrass	N
Schizachyrium scoparium	Little Bluestem	N	*Sorghastrum nutans*	Indiangrass	N	*Sorghastrum nutans*	Indiangrass	N
Cynodon dactylon	Bermudagrass	IN	*Bothriochloa ischaemum*	K.R. Bluestem	IN	*Bothriochloa ischaemum*	K.R. Bluestem	IN
			Dicanthium annualatum	Kleberg Bluestem	IN	*Dicanthium annualatum*	Kleberg Bluestem	IN
			Sorgum halapense	Johnsongrass	IN	*Sorgum halapense*	Johnsongrass	IN
Forbs			**Forbs**					
Desmanthus illinoensis	Illinois Bundleflower	N	*Ambrosia trifida*	Giant Ragweed	N	*Ambrosia trifida*	Giant Ragweed	N
			Croton glandulosus	Tropic Croton	N	*Croton glandulosus*	Tropic Croton	N
			*Desmanthus illinoensis**	Illinois Bundleflower	N	*Desmanthus illinoensis**	Illinois Bundleflower	N
			Helianthus annuus	Common Sunflower	N	*Helianthus annuus*	Common Sunflower	N
			Monarda citridora	Horsemint	N	*Monarda citridora*	Horsemint	N
			Plantago patagonica	Bristle-brach Plantain	N	*Plantago patagonica*	Bristle-brach Plantain	N
			Schrankia uncinata	Sensitive Briar	N	*Schrankia uncinata*	Sensitive Briar	N
			Verbena halei	Texas Vervain	N	*Verbena halei*	Texas Vervain	N
			Ipomoea sp.	Morning Glory	IN	*Ipomoea* sp.	Morning Glory	IN
			Sebania sp.	Rattlebush	IN	*Sebania* sp.	Rattlebush	IN
			Unidentified Forb 1			Unidentified Forb 1		
			Unidentified Forb 2			Unidentified Forb 2		

N: Native, IN: Introduced
* Seeded species occurring in 2007

APPENDIX F. EROSION CONTROL TESTING RESULTS FOR EXISTING AND NEW PLOTS

	Plot	Slope	Flow rate (GPM)	Dry Loss (lb)	Dry Loss (kg)	Dry Loss (lb/100 ft^2)	Dry Loss (kg/100 m^2)
Existing Sand Plots							
10/21/2004	Crownvetch	3:1	78.9	0.000	0.000	0.000	0.000
	Native Forbs/Grasses	3:1	78.9	0.000	0.000	0.000	0.000
	Wildflower Mix	3:1	78.9	0.000	0.000	0.000	0.000
	Native Grasses	3:1	78.9	0.300	0.111	0.023	0.111
	Bermudagrass	3:1	78.9	0.000	0.000	0.000	0.000
	Average			0.060	0.022	0.005	0.022
10/26/2004	Crownvetch	3:1	78.9	0.086	0.032	0.006	0.032
	Native Forbs/Grasses	3:1	78.9	0.592	0.219	0.045	0.219
	Wildflower Mix	3:1	78.9	0.000	0.000	0.000	0.000
	Native Grasses	3:1	78.9	0.164	0.061	0.012	0.061
	Bermudagrass	3:1	78.9	0.000	0.000	0.000	0.000
	Average			0.168	0.062	0.013	0.062
11/17/2006 (Mowed)	Crownvetch	3:1	78.9	0.015	0.007	0.002	0.011
	Native Forbs/Grasses	3:1	78.9	0.088	0.040	0.013	0.065
	Wildflower Mix	3:1	78.9	0.000	0.000	0.000	0.000
	Native Grasses	3:1	78.9	0.000	0.000	0.000	0.000
	Bermudagrass	3:1	78.9	0.000	0.000	0.000	0.000
	Average			0.021	0.009	0.003	0.015
11/17/2006 (Unmowed)	Crownvetch	3:1	78.9	0.063	0.029	0.010	0.047
	Native Forbs/Grasses	3:1	78.9	0.000	0.000	0.000	0.000
	Wildflower Mix	3:1	78.9	0.000	0.000	0.000	0.000
	Native Grasses	3:1	78.9	0.000	0.000	0.000	0.000
	Bermudagrass	3:1	78.9	0.000	0.000	0.000	0.000
	Average			0.013	0.006	0.002	0.009
New Sand Plots							
10/26/2006 (Mowed)	Plot 1	3:1	78.9	20.080	9.108	3.042	14.854
11/03/2006 (Mowed)	Plot 2	3:1	78.9	15.490	7.026	2.347	11.459
	Plot 3	3:1	78.9	2.630	1.193	0.398	1.946
	Plot 4	3:1	78.9	8.120	3.683	1.230	6.007
	Plot 5	3:1	78.9	19.470	8.831	2.950	14.403
	Plot 6	3:1	78.9	46.190	20.951	6.998	34.170
	Average			18.663	8.466	2.828	13.806
10/26/2006 (Unmowed)	Plot 1	3:1	78.9	20.080	9.108	3.042	14.854
11/03/2006 (Unmowed)	Plot 2	3:1	78.9	15.490	7.026	2.347	11.459
	Plot 3	3:1	78.9	2.630	1.193	0.398	1.946
	Plot 4	3:1	78.9	8.120	3.683	1.230	6.007
	Plot 5	3:1	78.9	19.470	8.831	2.950	14.403

	Plot 6	3:1	78.9	46.190	20.951	6.998	34.170
	Average			18.663	8.466	2.828	13.806
Existing Clay Plots							
11/04/2004	Crownvetch	2:1	52.6	0.000	0.031	0.000	0.000
	Native Forbs/Grasses	2:1	52.6	0.000	0.069	0.000	0.000
	Wildflower Mix	2:1	52.6	0.000	0.042	0.000	0.000
	Native Grasses	2:1	52.6	0.000	0.028	0.000	0.000
	Bermudagrass	2:1	52.6	0.000	0.118	0.000	0.000
	Average			0.000	0.058	0.000	0.000
11/09/2004	Crownvetch	2:1	52.6	0.000	0.025	0.000	0.000
	Native Forbs/Grasses	2:1	52.6	0.000	0.051	0.000	0.000
	Wildflower Mix	2:1	52.6	0.000	0.046	0.000	0.000
	Native Grasses	2:1	52.6	0.000	0.013	0.000	0.000
	Bermudagrass	2:1	52.6	0.000	0.009	0.000	0.000
	Average			0.000	0.029	0.000	0.000
11/17/2006 (mowed)	Crownvetch	2:1	52.6	0.000	0.000	0.000	0.000
	Native Forbs/Grasses	2:1	52.6	0.000	0.000	0.000	0.000
	Wildflower Mix	2:1	52.6	0.000	0.000	0.000	0.000
	Native Grasses	2:1	52.6	0.000	0.000	0.000	0.000
	Bermudagrass	2:1	52.6	0.000	0.000	0.000	0.000
	Average			0.000	0.000	0.000	0.000
11/17/2006 (Unmowed)	Crownvetch	2:1	52.6	0.000	0.000	0.000	0.000
	Native Forbs/Grasses	2:1	52.6	0.000	0.000	0.000	0.000
	Wildflower Mix	2:1	52.6	0.000	0.000	0.000	0.000
	Native Grasses	2:1	52.6	0.000	0.000	0.000	0.000
	Bermudagrass	2:1	52.6	0.000	0.000	0.000	0.000
	Average			0.000	0.000	0.000	0.000
New Clay Plots							
11/17/2006 (Mowed)	Plot 1	3:1	78.9	2.230	1.012	0.338	1.650
	Plot 2	3:1	78.9	0.320	0.145	0.048	0.237
	Plot 3	3:1	78.9	0.420	0.191	0.064	0.311
	Plot 4	3:1	78.9	0.650	0.295	0.098	0.481
	Plot 5	3:1	78.9	1.700	0.771	0.258	1.258
	Plot 6	3:1	78.9	0.830	0.376	0.126	0.614
	Average			1.025	0.465	0.155	0.758
11/17/2006 (Unmowed)	Plot 1	3:1	78.9	2.240	1.016	0.339	1.657
	Plot 2	3:1	78.9	5.110	2.318	0.774	3.780
	Plot 3	3:1	78.9	4.160	1.887	0.630	3.077
	Plot 4	3:1	78.9	0.360	0.163	0.055	0.266
	Plot 5	3:1	78.9	7.310	3.316	1.108	5.408
	Plot 6	3:1	78.9	2.370	1.075	0.359	1.753
	Average			3.592	1.629	0.544	2.657