Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-11/0-5731-1		

4. Title and Subtitle
SYNTHESIS AND STUDY OF THE ROADSIDE VEGETATION ESTABLISHMENT PROCESS

5. Report Date
Published: May 2011

6. Performing Organization Code

7. Author(s)
B.J. Storey, J.R. Schutt, J.A. McFalls, K.D. Jones, A.P. Garza, T.A. Gaus, G. Marek, K. Heflin, W.J. Rogers, and C. Robinson

8. Performing Organization Report No.
Report 0-5731-1

9. Performing Organization Name and Address
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
Project 0-5731

12. Sponsoring Agency Name and Address
Texas Department of Transportation
Research and Technology Implementation Office
P.O. Box 5080
Austin, Texas 78763-5080

13. Type of Report and Period Covered
Technical Report:
September 2006–August 2010

14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Synthesis and Study of the Establishment and Management of Roadside Vegetation
URL: http://tti.tamu.edu/documents/0-5731-1.pdf

16. Abstract
The Texas Pollutant Discharge Elimination System (TPDES), which is administered and enforced by the Texas Commission on Environmental Quality (TCEQ), requires perennial vegetation to 70 percent of native or adjacent background vegetation before a Notice of Termination (NOT) can be filed. The Texas Department of Transportation's (TxDOT) roadway projects often terminate at times of the year when establishing permanent vegetation is very difficult or nearly impossible. Even when the construction calendar and the ideal growing season line up, establishing vegetation is still a constant challenge. Regions of the state that have limited rainfall and a shorter growing season often take multiple years to establish vegetation to meet the TPDES requirements.

The objective of this study was to provide a more diverse set of tools and options for TxDOT personnel that will help ensure timely vegetation establishment to meet the TPDES regulatory requirements, minimize project delays, and help reduce long-term costs in vegetation development and management. To achieve these objectives, the researchers: (1) compared TxDOT's practices compare to those of other state departments of transportation (DOTs) and related fields, (2) identified methods for more rapid vegetation establishment for meeting the TPDES requirements using field demonstration plots seeded according to current TxDOT practices, (3) devised a tool to assist design personnel not familiar with the vegetation establishment process, and (4) developed a vegetation establishment field guidebook.

17. Key Words
Vegetation Establishment, Roadside Seeding, Re-Vegetation

18. Distribution Statement
No restrictions. This document is available to the public through NTIS:
National Technical Information Service
Alexandria, Virginia 22312
http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	112	

SYNTHESIS AND STUDY OF THE ROADSIDE VEGETATION ESTABLISHMENT PROCESS

by

Beverly J. Storey
Associate Research Scientist
Texas Transportation Institute

James R. Schutt
Assistant Research Scientist
Texas Transportation Institute

Jett A. McFalls
Associate Research Scientist
Texas Transportation Institute

Kim D. Jones
Assistant Professor
Texas A&M University - Kingsville

Abel P. Garza
Research Assistant
Texas A&M University - Kingsville

Teresa A. Gaus
Graduate Student
West Texas A&M University

Gary Marek
Graduate Student
West Texas A&M University

Kevin Heflin
Graduate Student
West Texas A&M University

William J. Rogers
Assistant Professor
West Texas A&M University

Clay Robinson
Associate Professor
Texas A&M University - Kingsville

Report 0-5731-1
Project 0-5731
Project Title: Synthesis and Study of the Establishment and Management of Roadside Vegetation

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: May 2011

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

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.

The researchers in charge of the project were James R. Schutt and Beverly J. Storey.

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.

ACKNOWLEDGMENTS

The authors thank the Project Director Chris Chambers, the Project Monitoring Committee consisting of Ethan Beeson, Steve Prather, Ann Finley, Michael Alford, Nancy Fisher, Marvin Hatter, and Laurie Williams. The authors also thank Duncan Stewart for providing outstanding support and advice throughout this project. Special thanks also go to the Vegetation Management Section and TxDOT district personnel for their time and effort which contributed to the project's success.

We also recognize the Arizona Department of Transportation (DOT), Arkansas State Highway and Transportation Department, California DOT, Florida DOT, Oklahoma DOT and New Mexico DOT for their assistance.

Finally, we express our appreciation to TxDOT and the Federal Highway Administration for their financial sponsorship of the project.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1 INTRODUCTION

BACKGROUND

Vegetation Establishment's Role in Regulatory Compliance

Vegetation establishment is part of the Texas Department of Transportation's (TxDOT) Storm Water Management Program, which is designed to conform to the rules and regulations set forth by the Texas Pollutant Discharge Elimination System (TPDES). It is the means by which TxDOT meets its obligations as prescribed by Section 402 of the Federal Clean Water Act as administered by the Texas Commission on Environmental Quality (TCEQ). The TCEQ oversees these responsibilities through its General Permit to Discharge Wastes TXR150000, generally referred to as the Construction General Permit (CGP) which applies to TxDOT's construction activities. A Storm Water Pollution Prevention Plan (SW3P) addresses temporary erosion and sediment control measures for a construction site and is required on all projects with more than one acre of disturbed land. According to the CGP issued in 2008, a Notice of Termination (NOT: a written submission to the executive director from a discharger authorized under a general permit requesting termination of coverage) must be submitted when site conditions meet any of the following:

- Final stabilization has been achieved on all portions of the site that are the responsibility of the permittee.
- A transfer of operational control has occurred.
- The operator has obtained alternative authorization under an individual TPDES permit or alternative TPDES general permit (*1*).

For TxDOT projects, final stabilization involves the establishment of perennial vegetation as a permanent erosion control measure. The CGP states that final stabilization occurs when the following conditions on the construction site are met:

- All soil disturbing activities at the site have been completed and a uniform (i.e., evenly distributed, without large bare areas) perennial vegetative cover with a density of at least 70 percent of the native background vegetative cover for the area has been established on all unpaved areas and areas not covered by permanent structures, or equivalent permanent stabilization measures (such as the use of riprap, gabions, or geotextiles) have been employed.

- In arid, semi-arid, and drought-stricken areas only, all soil disturbing activities at the site have been completed and both of the following criteria have been met:
    - Temporary erosion control measures (e.g., degradable rolled erosion control product) are selected, designed, and installed along with an appropriate seed base to provide erosion control for at least three years without active maintenance by the operator.
    - The temporary erosion control measures are selected, designed, and installed to achieve 70 percent vegetative coverage within three years (*1*).

According to the TxDOT *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges, Item 506 Temporary Erosion, Sedimentation and Environmental Controls,* projects "will not be accepted until a 70 percent density of existing adjacent undisturbed areas is obtained, unless otherwise shown on the plans. When shown on the plans, the Engineer may accept the project when adequate controls are in place that will control erosion, sedimentation, and water pollution until sufficient vegetative cover can be established" (*2*). The TxDOT *Storm Water Management Guidelines for Construction Activities* (*3*) states that "when estimating vegetative cover for the purposes of determining final stabilization, the percentage should be relative to the existing natural vegetative cover in an adjacent undisturbed area. Where an exposed area is naturally stable with little or no vegetative cover (e.g., rock outcrop), the area can be considered stabilized for the purpose of the Construction General Permit requirements."

One of the problems facing TxDOT regarding filing the NOT is that construction activities are often completed before the site has had adequate time to establish vegetation. This may be due to project delays that postpone planting operations until the optimal growing season has passed, the project terminates in hot, dry weather, and/or vegetation establishment takes multiple years to reach the TPDES CGP requirements (70 percent coverage relative to adjacent area). Releasing the contractor prior to the submission of the NOT may occur in some instances. "The continuation of the SW3P until submittal of the NOT can be by State Forces (Item 261 – State Force Account – Maintenance of Storm Water Pollution Prevention Plan), maintenance contract or another construction-type contract" (*3*). However, make effort to ensure that the stabilization requirements listed in the previous section are met prior to releasing the contractor to further reduce the commitments and expenditures of the Department. The *Storm Water Management Guidelines for Construction Activities* (*3*) contains further information.

In most instances, seeding is the primary means of establishing vegetation on construction projects. Vegetation establishment plans and specifications for construction sites are developed and then submitted for review/approval. TxDOT's *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* specifies bid items (*2*). Designers choose pay items pertaining to the vegetation establishment process from the Description Chart Code and include them as part of the design plans. For example, Item 164 Seeding for Erosion Control is the bid item and 0164-2001 BROADCAST SEED (PERM) (RURAL) (SANDY) is one of several pay items used under this bid item. Designers select pay items best suited for the each project according to factors such as location and growing season of the scheduled work. They also select the seed application method for the project. General notes contain supplemental instructions not in the specifications. Even with the correct seed mixture and rate, and planting, adequate coverage may take more than a single growing season to become established in the semi-arid and arid portions of the state.

Underlying Principles

Roadways have a large impact on the surrounding environment. Mitigating these impacts is an important and demanding task regulated by various local, state, and federal agencies. These impacts are evident in the air quality surrounding the roadway, the quality of water runoff, and its visual appearance. The most critical impacts, however, are those affecting the safety of the highway user.

The critical common issue that protects the roadway infrastructure is a stable ground surface. This stabilization is accomplished primarily by grassy vegetation unless the area is covered by a structure, impervious surface (concrete, riprap, etc.), or permanent stabilization such as channel lining materials. Well-developed roadside grass communities are indispensable to making a highway sustainable in its ability to create a safe environment for the driver, maintain minimal environmental impact, and still be accomplished within acceptable economic resources.

The discipline of seeding establishment has acquired a distinct character in three areas of activity: agriculture, reclamation, and urban development. Most research into grass establishment has been directed toward agricultural settings and goals. These applications focus on cereal grains, grazing pastures, preservation of fallow fields, and protection of drainage ways. The range of seeded varieties is typically small and focuses on those grasses that are most palatable for forage, or which cost less and are widely available. The equipment for seeding is tailored to smooth-bodied seeds and less to the fluffy or hairy nature of many native grass varieties.

The other distinct area of vegetation establishment research is reclamation of mining and drilling sites. While the techniques used in vegetation establishment for such sites are similar to those found in agriculture, this practice typically deals with large areas of highly disturbed soils, and/or reconsolidated soils. The seed varieties used include a more diverse list in which native species dominate. The native seed varieties tend to have smaller seeds and fluffy or hairy seeds which may require the use of specialized seeding equipment that will accommodate such seed mixtures.

Grass establishment in developed areas also has its own particular needs and goals. These areas include city and suburban green spaces such as medians, roadsides, parks, golf courses, business properties, and private residences. Grass vegetation in these areas is commonly comprised of only a couple of species that are usually maintained in a manner to reduce invasion by other, weedy species. Seeding in developed areas often occurs in relatively small areas with good access to supplemental water. Sod is a frequent alternative to seeding where appearance or erosion control is required and budgets are adequate.

Of these three areas of application, the techniques used in reclamation and in developed areas bear the most similar goals and context to that of the highway roadway. Typical roadside soils are often highly disturbed. Their original soil horizons are usually destroyed and finished slopes are designed to quickly remove stormwater runoff from the sites rather than infiltrate for long-term plant use (*4*). Rural construction sites are often distanced from easily attainable water sources and the acreage involved is typically large, sometimes hundreds of combined acres. On the other hand, since urban re-vegetation must meet the expectations of the community, practices typical of developed areas are commonly implemented in urban areas.

Clearly, there is significant variation between urban and rural contexts and this variation impacts the management and execution of vegetation establishment projects. In most instances, seeding is the primary means of establishing vegetation on TxDOT construction projects and can be problematic. Despite the difficulties of conducting this task, TxDOT and all of its 25 districts have been successful in meeting regulatory agencies' requirements while achieving the long-term sustainable roadside condition. Across the state, differences in climate (temperature, precipitation), geology (soil, rock), eco-zone (adaptable plant species, natives), urbanization (urban, suburban, rural), and social (aesthetics, public opinion) are additional challenges in establishing vegetation.

RESEARCH OBJECTIVES

The objectives of this study were to examine the current procedures and process for vegetation establishment and identify any areas or issues that can be improved to provide a more diverse set of tools and options for TxDOT personnel. Accomplishing this will help ensure timely vegetation establishment to meet the TPDES regulatory requirements, minimize project delays, and help reduce long-term costs in vegetation development and management. This study also looked at the factors affecting new vegetation establishment on roadway construction projects. While the current TxDOT standard specifications have been designed to cover all aspects of needs for the entire state on roadside vegetation management, there are evolving specific factors discovered by TxDOT local districts and area offices that have not been addressed, particularly the issue of the CGP NOT. As a result, local districts are investing time and effort in searching and experimenting with alternatives that will satisfy their unique needs. To address these issues, this project examined the variables, and factors that lead to successes or failures from sources within TxDOT and the wider industry as well. The project identified methods for more rapid vegetation establishment for meeting the TPDES requirements using field demonstration plots seeded according to current TxDOT practices. Furthermore, the study developed tools evolved from the synthesis of information devised to:

- Assist the designer in their decision-making process when determining best practices for roadsides vegetation establishment.
- Provide a quick field reference for TxDOT pay items and issues directly related to roadside vegetation establishment.

The study is not intended to alter the current specifications, but to synthesize information from various sources, including TxDOT districts, neighboring state DOTs and other entities. The project not only provides support for TxDOT's mission on roadside vegetation establishment and management, but also creates training and educational tools to enhance the understanding of the vegetation establishment process.

CHAPTER 2 LITERATURE REVIEW

The research team reviewed TxDOT's and other DOT manuals and practices, and the current literature related to seeding establishment to determine if TxDOT's procedures reflect best practices. How do TxDOT's practices compare to other state transportation agencies?

EXISTING TXDOT MANUALS, GUIDELINES, AND SPECIFICATIONS

Manuals, guidelines and specifications are widely available and while they typically reflect traditional practices, they are very location-specific. Once established by experience, the procedure outlined in the documents may change little over time. Despite the local references, when viewed as a group, similarities in practice indicate proven fundamentals. The research team reviewed federal and state regulations, TxDOT pay items, vegetation establishment design, and administration and construction procedures to assess how TxDOT establishes roadside vegetation during and after construction projects. TxDOT details the standard specifications for establishing roadside vegetation and landscaping in the specifications listed in the department's specifications book entitled: *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* (*2*) or 'spec book' as it is often called. TxDOT manuals pertaining to the design implementation of these standard specifications as related to vegetation establishment include, but are not limited to:

- *A Guide to Roadside Vegetation Establishment.*
- *Storm Water Management Guidelines for Construction Activities.*
- *Storm Water Field Inspector's Guide.*
- *Environmental Manual.*
- *Plans, Specifications and Estimates (PS&E) Preparations Manual.*
- *Geotechnical Manual.*
- *Maintenance Operations Manual.*
- *Design and Construction Information System Manual.*
- *Landscape and Aesthetics Design Manual*.

Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges

Discussion throughout this project led to many existing TxDOT documents that contain a great deal of information regarding vegetation establishment and/or re-establishment, and the connection to state and federal regulations. TxDOT spells out the requirements in the spec book. The spec book is broken down into pay items with clearly stated details on the item's use and payment method. The spec book also has numerous district and statewide special specifications (SS) and special provisions (SP). A special specification is used when a process or item not contained in the spec book is either generally new to TxDOT or needs to be used on a specific project. A special provision is used to amend or replace part of an existing item in the spec book. Some special provisions are required statewide on all projects and others are optional if the designer requires that specific use.

For the purpose of this report, vegetation establishment and/or the re-vegetation of an area generally refers to the establishment of a perennial or permanent grass cover as it relates to the requirements of the TPDES CGP. The current items most often associated with the vegetation establishment process include:

- Item 100 Preparing Right of Way.
- Item 110 Excavation.
- Item 134 Backfilling Pavement Edges.
- Item 160 Topsoil.
- Item 161 Compost.
- SP 161-001.
- SS 1011 Compost Mulch Filter Berm.
- Item 162 Sodding for Erosion Control.
- Item 164 Seeding for Erosion Control.
- 164.3.A Broadcast Seeding.
- 164.3.C Cellulose Fiber Mulch.
- 164.3.D Drill Seeding.
- SP 164-004 Bonded Fiber Matrix
- SP 164-04 Vertical Tracking.

- Item 166 Fertilizer.
- SP 166-001.
- Item 168 Vegetative Watering.
- Item 169 Soil Retention Blankets.
- SP 169-002.
- Item 314 Emulsified Asphalt Treatment.
- Item 506 Temporary Erosion, Sedimentation, and Environmental Controls.
- SP 506-013.

There are Special Specifications for statewide use, including SS 1018 Tree Protection. Numerous districts have special specifications that relate to district-specific use or to a specific project. The designer should always check for any district-specific requirements pertaining to vegetation establishment during the design decision process.

Although the spec book outlines the requirements of the specific item, there is little guidance given on how to use these items within the design process to ensure that vegetation establishment occurs in a timely and effective manner. There are three TxDOT documents that have a great deal of information required for growing grass on the roadside during and after construction activity: *A Guide to Roadside Vegetation Establishment, Storm Water Management Guidelines for Construction Activities*, and *Storm Water Field Inspector's Guide.*

A Guide to Roadside Vegetation Establishment

This TxDOT document is very useful in its approach to discussing vegetation establishment. Not only does it provide guidance on the 'how to,' it provides the 'why' as well. "Topsoil is the single most important factor in establishing and promoting vegetation on construction sites. When placing topsoil on a construction area, the soil used must be just that…topsoil. Sometimes sub-soil is mistakenly brought to the ground surface in some areas. These areas will have poor vegetation and will be prone to erosion" (*5*). This manual discusses everything from sunlight under bridges to planting procedures for construction operations and is recommended reading for designers tasked with establishing vegetation on a construction site.

Storm Water Management Guidelines for Construction Activities

The information outlined in the *Storm Water Management Guidelines for Construction Activities* (*3*) includes most topics related to re-vegetation after construction activities and how these relate to the specific regulatory requirements for the site. Chapter 2.0 Storm Water Pollution Prevention Plans discusses the SW3P contents to include how the site will meet the regulatory requirements for stabilization practices (usually accomplished by vegetation):

> The major considerations in the development of an effective and economical SW3P are:
>
> - Project sequencing and phasing.
> - Grade management.
> - Drainage features.
> - Limiting disturbed areas.
> - **Stabilization practices.**
> - Storm water management.
> - Basic principles of the erosion and sedimentation process.

Of particular interest are Chapter 8 Preconstruction Conference Requirements and Chapter 9 Completion of Project and Release of Contractor. The preconstruction conference is an important opportunity for TxDOT to clearly outline the contractor's responsibilities for re-establishing vegetation as part of the regulatory requirement of the CGP and as part of the contractual agreement with TxDOT for completion of the project. The entirety of Chapter 8 is contained below:

> The preconstruction Conference shall include a review of environmental concerns, the SW3P, and permanent erosion control measures, and includes:
>
> - Possible conflicts between the Contractor's schedule of work and the SW3P.
> - Installation of and payment for the various erosion control devices and procedures.

- Schedule and unscheduled joint field reviews or erosion control devices.
- The Contractor shall submit a list of erosion control measures to be installed and maintained along with the name of the Contractor and/or Subcontractor that will be responsible for installing and maintaining the device and/or measures.

Additionally the following item should be included:

- The District Engineer's Statement designating the Department's person who will be responsible for making the project site inspections, as discussed in Section 7.0. This statement by the District Engineer will be included as part of the SW3P.

Chapter 9 defines 'final stabilization' and how this will affect contractor obligations for the project. As stated earlier, the research team recommends that the preconstruction conference should include pertinent discussion regarding vegetation's role in regulatory compliance and final stabilization of the site.

Storm Water Field Inspector's Guide

The TxDOT *Storm Water Field Inspector's Guide* (*6*) provides more detailed descriptions of the various methods available for use to meet the SW3P requirements. The Guide advises the inspectors regarding the use of erosion and sediment control best management practices (BMP) during and after construction activity. This handbook is a companion document to the *Storm Water Management Guidelines for Construction Activities*.

Other TxDOT manuals contain pieces of information regarding vegetation. However, many of these manuals are more specific to landscape plantings and vegetation management rather than vegetation establishment (seeding).

INTERPRETING THE LITERATURE

The approach of the research team was to identify the types of research associated with roadside vegetation establishment. These include:

- Previous TxDOT Research.
    - TxDOT has funded numerous research projects relevant to the goals of this study. These were reviewed and are discussed in this report.
- Environmental and Ecological Research.
    - Sources in the environmental and ecological research area include a large amount of basic research with detailed scientific studies that provide underlying principals rather than best practices for general use. As these principals recur in other studies, patterns can become clearer and are applied toward solving specific problems.
- Academic and Extension Agency Research and Implementation.
    - University-based research includes detailed scientific studies but also focuses heavily on implementation and relatedness to on-the-ground issues.
- Industry Trade Associations.
    - Industry trade associations usually have a very narrow focus of practices but usually reflect current practice. Many of these types of references are anecdotal rather than controlled studies.

When reviewing current practice, it is tempting to make comparisons that may not be directly related. For example, the basis of seeding practices for highways often comes from agricultural research and experience. Indeed, there are some important similarities but there are also striking differences as well. Different agencies often have different goals and timeframes. They may employ different methods for their environment and they may be funded differently. Consequently, when comparing one program to another, it is important to make allowances for these differences.

The research team compared the areas of information to help characterize the available knowledge and its applicability to the unique conditions of the highway. The variety of practice of vegetation establishment may be grouped based on the relative scales of size, time, and money. Table 1 compares the following:

- Agriculture (range and pasture).
- Restoration (habitat or historic plant communities).
- Reclamation (usually serious disturbances such as mining).

- Construction (re-establishment/repairing construction-related damage).
- Turf (parks, play fields, home, golf course, other public uses).

Table 1. Comparison of Goals and Approaches to Vegetation Establishment.

	Agriculture	Restoration	Reclamation	Construction	Turf
Site Size	Tens to hundreds of acres	Small site to few acres, some in hundreds of acres	Usually many acres	Small sites to many acres	Very small to a few acres, large for some projects
Project Goals	High production over long term	Recreate historic vegetation community.	Establish a functioning landscape and vegetation community	Rapid repair of disturbed areas	Safe attractive grass surface for human activities
Time Frame	Years	Years	Years	Months	Weeks
Funding	Mostly borne by single owner	Small groups, non-profits, universities	Large private companies	Private companies	Owners, private business, municipalities
Type of Seed	Native & non-native	Collected native	Natives preferred	Natives, non-natives	Typically non-native sod-forming
Number of Species	Few, usually grasses	Wide variety of all types grass, shrubs, trees	Few of all types grass shrubs, trees	Few, usually grasses	Single
Seeding Rates	Low due to costs	Medium in large sites to high in small sites	Low due to large areas and costs	Low to medium	High
After-Care	Varies with size; fertilization, grazing, haying	No supplemental resources; may remove invaders	Little to none	Little to none	High: fertilization, watering, mowing

Roadside projects appear to fall mostly into the construction category. This category includes large private and corporate construction projects and federal, state, county, and city projects. These types of projects are subject to close oversight for compliance to government regulations as are most other types of projects. However, since the agencies themselves are the source of the rule, they receive closer oversight and, due to their size, are the ones most likely to rely on comprehensive guidelines and manuals.

Despite the differences in scale, funding, and timeframe, it is important to remember that roadside vegetation establishment is a natural process. Therefore, some aspects of each category will have application for use in other fields. It is most notable that different goals, timeframes, and budgets will ultimately determine the most appropriate practice. Some other aspects of this comparison will be discussed later.

For comparison in this study, highway-related projects are categorized as construction. This is because the timeframe of projects is relatively short (duration of construction), and the primary goal is effective short and long-term soil stabilization rather than establishing a plant community with a particular composition for habitat value (as do restoration and reclamation). Agricultural interests must typically deal with long-term programs and turf industries deal with very short and budget-intensive programs.

Previous TxDOT Research

TxDOT has invested in research for all phases of highway development and management, including roadside vegetation. The research team reviewed all TxDOT-funded research studies for their relevance to this study.

Early studies address seeding issues and some of this information assisted the later development of TxDOT's seeding program. Many early studies focused on herbicide types and their rates of application. After the development of Federal requirements for stricter erosion control procedures, studies began to center on erosion control materials, methods, and practices, including vegetation. Compost became a subject in several studies. The most recent studies reviewed compost usage and the role and use of native grass species in roadside plant community development.

Table 2 lists the past research funded by TxDOT that has relevance to the intent of this study. Erosion control studies were excluded since they did not deal with seeding and germination. A brief summary of each study follows Table 2.

Table 2. TxDOT Funded Research in Vegetation Management.

Date	Title	Authors	Agency
1968	67-7, *Establishment of Bermudagrass Seeded with Annual Ryegrass*	Bowmer & McCully	Texas Transportation Institute
1970	142-1, *Problems in Establishing or Maintaining Vegetation on Roadsides*	McCully, et al.	Texas Transportation Institute
1972	142-3, *Establishment and Management of Roadside Vegetation*	McCully & Stubbendieck	Texas Transportation Institute
1976	182-2F, *Establishment and Management of Roadside Vegetation*	Allen & McCully	Texas Transportation Institute
1984	902 A-1, *Potential for Using Mycorrhizal Plants to Revegetate Texas Highway Right of Ways*	Davies & McCully	Texas Transportation Institute
1986	902-3, *Enhancement of Texas Highways Vegetation with Mycorrhizal Fungi*	Davies & McCully	Texas Transportation Institute
1986	902-4, *Propagation of Wildflowers for Roadside Use*	McCully, et al.	Texas Transportation Institute
1986	902-5, *Propagation of Some Native Woody Landscaping Plants*	McCully, et al.	Texas Transportation Institute
1994	944-1, *Prairie Restoration: An Evaluation of Techniques for Management of Native Grass Communities in Highway Roadsides in Texas*	Schutt & Teal	Texas Transportation Institute
1994	902-6, *Establishment of Grass Mixtures on Roadsides*	Simpkins	Texas Transportation Institute
2003	0-4571-1, *Utilizing Compost as an Alternative Method to Standard Seedings: Final Report*	Fedler, et al.	Center for Multidisciplinary Research in Transportation
2007	0-5212-1, *Comparison of TxDOT Seeding Mixes and Fertilizer Rates to the Use of Native Grass*	McFalls, et al.	Texas Transportation Institute
2007	0-4949, *Successional Establishment, Mowing Response, and Erosion Control Characteristics of Roadside Vegetation*	Li, et al.	Texas Transportation Institute

The research for *Establishment of Bermudagrass Seeded with Annual Ryegrass* is based on a once-used practice within TxDOT to seed unhulled (hulls left on the seed) bermudagrass with annual ryegrass. The central problem with this method is that the ryegrass creates a dense cover and prevents the bermudagrass from germinating. The study tested various seed rates for ryegrass and a range of herbicides to set back the ryegrass. The recommendations focus on timely applications of herbicide. Mowing was also suggested but researchers noted that it required more frequent treatments to be effective. The report notes that this practice is limited to the eastern portion of Texas (*7*).

Issues related to vegetation establishment or management were studied in *Problems in Establishing or Maintaining Vegetation on Roadsides* at seven sites located in Taylor, Brazos, Rusk, Burleson, Hidalgo, Webb, and Grayson counties. The study included:

- Issues related to establishing grass in high PI (plasticity index) soils (very low pH).
- Tests using buffalograss as a seed mix component and recommendations that it be planted as part of a seed mix rather than seeded alone.
- Tests of and recommendations for herbicides to control perennial weeds growing in asphalt shoulder pavements.
- Tests on chemical control of plants interfering with mowing near median barriers.

Results of the high PI, low pH soils part of the research demonstrated that soils enhanced with amendments such as gypsum, cationic polymers, and polyurethane showed some improvement but were not universally effective. Natural organic materials such as composted garbage were ineffective and at heavy rates were detrimental. The researchers recommended a lime application rate of up to 50 tons per acre followed by repeat applications after the first three years (*8*).

The study, *Establishment and Management of Roadside Vegetation,* is a continuation of the 1970 study and provides more detail to the field data collected. The recommendations and initial findings are unchanged (*9*).

Research results generated from 182-2F, *Establishment and Management of Roadside Vegetation* showed that:

- Straw mulch proved more effective in erosion control than re-claimed paper mulch in East Texas. Straw mulch anchored by asphalt or latex was significantly superior to resin-anchored straw mulch.
- Bermudagrass and weeping lovegrass were the most effective species tested for re-vegetating acidic soil slopes.
- Water-degradable polymer additive to trichloroacetic acid (TCA) at 18 lb TCA/ft mile was significantly superior to TCA at a 24 lb/ft mile rate 60 days following treatment.
- The herbicide glyphosate can control African Rue.
- Velpar proved to be an effective herbicide for the general control of unwanted vegetation along roadways (*10*).

Potential for Using Mycorrhizal Plants to Revegetate Texas Highway Right of Ways (*11*) is a short report of early studies that set the stage for the more in-depth study that followed in 1986. The research conducted for 902-3, *Enhancement of Texas Highways Vegetation with Mycorrhizal Fungi* compared the reaction of a range of plant species and types to the addition of Mycorrhizal fungi. The report is detailed and includes comparisons of green sprangletop, sideoats grama, bermudagrass, Chinese tallow, live oak, and Texas mountain laurel. Although the report noted that "there are advantages in utilizing Mycorrhizal fungi" more research was needed and did not make any specific recommendations for rates or application methods (*12*).

The study, *Propagation of Wildflowers for Roadside Use,* tested the germination parameters for bluebonnets, beach morning glory and numerous other wildflower species (*13*).

Propagation of Some Native Woody Landscape Plants is "a report of research progress on plant propagation which has not progressed to the point of implementation." Plants studied included sand sagebrush, mountain mahogany, little walnut, black walnut, bur oak, Eve's necklace, and rusty blackhaw (*14*).

The intent of the study, *944-1 Prairie Restoration: An Evaluation of Techniques for Management of Native Grass Communities in Highway Roadsides in Texas,* was to monitor roadside plots seeded with various native grass mixtures for their development under mowing and other disturbances. However, researchers canceled the study after construction and landowner activities destroyed a great number of the plots (*15*).

Various grass species located at sites near Coleman, Lufkin, Odessa, and Tulia were researched in *902-6, Establishment of Grass Mixtures on Roadside* and discussed in detail in the Natural Processes section of this report (*16*).

0-4571-1, Utilizing Compost as an Alternative Method to Standard Seedings: Final Report compared the establishment of seeded vegetation using different depths of compost mulches. The study found that "compost mulch greater than two-inch adversely affected emergence and establishment of desired vegetation" and that soil moisture retention was comparable on plots treated with straw mulch held in place by jute netting, compost manufactured topsoil, or a 4-inch layer of compost mulch" (*17*). The following section on natural process discusses this in further detail.

The effects of seeding native grasses in soils from sites around Abilene, Austin, Corpus Christi, Lufkin, and Georgetown were researched in *0-5212-1, Comparison of the Use of TxDOT Seeding Mixes and Fertilizer Rates to the Use of Native Grass.* The tests compared a special native seed mix to the current TxDOT seed mix and tested different seeding rates. The study also included a compost leachate component. The study found that the all-native mix established a lower percent of vegetative cover and that those natives that did do well are already in the TxDOT standard mix. The study also found that increasing the seed rates resulted in a flush of early growth but actually led to a lower percentage of cover later. The test was long enough to determine the long-term effects of this condition. Researcher did not treat the imported study soils prior to testing, resulting in the germination of large amounts of existing seed. In most cases, all seeded mixes were a small portion of the final, total vegetative cover (*18*).

This study, *0-4949, Successional Establishment, Mowing Response, and Erosion Control Characteristics of Roadside Vegetation,* investigated the contribution of existing and adjacent vegetation to roadside vegetation development. Surveys of long-established roadsides were conducted to assess the type of successional development that occurred since initial seeding.

With the exception of bermudagrass (part of the TxDOT seed program for many years) virtually none of the seeded species were present years after seeding. Instead, roadside plant communities showed a wide diversity of species, cool and warm season species, and forbs; none of which was planted. (Cool season grasses are generally described as those plants starting growth in late winter/early spring and continuing growth until hot, dry weather prevails. Growth usually resumes with cooler weather and rainfall. Warm season grasses are generally described as those plants initiating growth in the spring and continuing through the hotter weather). Findings suggest that the existing soil bank and the surrounding plant communities determine the future development of roadside plant communities more than the initial seeding after construction. These further suggest that seed mixes might be focused more on fast, initial cover for erosion control than on setting future community development trajectories (*19*).

Natural Processes

Although it may appear that vegetation can be managed through human intervention, the plants respond to a set of rules established over many eons. These rules are quite simple and never vary despite location, soil type, or the availability of resources. Understanding these rules enables establishment and management techniques that take maximum advantage of opportunities to solve environmental problems. The rules help prevent setting goals that counter the natural plant community processes.

The first rule has been referred to as the *law of constant yield* (*20*). The amount of vegetative production (carrying capacity of the site) is a function of the available resources. Resources principally include water, light, and nutrients necessary for plant growth and reproduction. Different sites have different levels or combinations of resources and therefore favor different plant species and plant types. The level of resources within any given area limits overall production to only that which can be supported. A related facet is that if resources are available, other species will make use of them.

The second rule is that of *change*, often referred to as succession. Disturbances, either planned or unplanned, in the local environment can cause changes in the plant community by eliminating some species while allowing others to flourish. As plant communities mature, they cause changes in the character of the site that will be more favorable for some species and less favorable for others. This results in a change in the composition of the plant community over time. An important driver of change is the third rule.

The third rule is that of *competition*. Competition is a natural process whereby some species gain a survival advantage by virtue of some factor of their form, or genetic ability to grow faster, use fewer resources, or access resources other species. The best example is that of sites being colonized very early by small-seeded, short-stature, tap-root type annual plants and over time slowly being dominated by large-seeded, tall-stature, fibrous-root type perennials. Researchers have long documented this process and the stages of this process are easily seen in many roadside sites.

These rules are always at work in highway roadsides because of their constant state of disturbance. These disturbances include maintenance practices such as mowing and herbicide application and other factors such as utility work, use by adjacent landowners, and damage by errant vehicles.

Competition

Competition is a key element of successional change in plant communities. For this reason, researchers frequently cited competition as a factor in establishing seed rates. Some seed will have more vigor, make better contact with the soil, or happen to access some resource better than other seeds and gain an advantage in establishment. As growth continues, larger more vigorous seedlings will dominate and crowd out their smaller neighbors. There will be a natural thinning until there is balance between biomass and soil resource.

Guidelines typically assume or recommend that seeding be applied to a well-prepared soil bed (*5,21, 22, 23*). This activity may include removing weedy growth, and having the soil tilled, amended, rolled and firmed. In a well-prepared site, more competition is likely to occur between the seeded species than with existing seed in the soil.

Additionally, most guidelines recommend after-care measures such as herbicides to control weed encroachment, the addition of fertilizer or water to later stages of growth (*21, 24*). The researchers interpret these guidelines to mean designers believe that undertaking such preparation measures will ensure a large percentage of seed germination and survival although this assumption is not explicitly stated. Conversely, other researchers have found that only 10–30 percent of planted seed produce seedlings of which less than 50 percent survive (*25, 26*). Typically, the researchers recommended adjusting the seed rate for any known, adverse condition that might result in lower survival but do not specify any certain amounts. Determining the specific rate is left to professional judgment.

A few authors, such as Steinbacher (*27*) and Cornell (*28*), note the advantages of conserving the existing topsoil for the seed, but none of them found made any allowances in the seed rate for seeds already present in the soil or those that may invade from other areas. It was noted that where weed competition is an issue, the seed rate might be adjusted upward to shift the competitive advantage to the seeded species (*29*).

Seeding in standing vegetation is not recommended where it can be avoided (*23*). However, seeding in very clean, prepared soil is widely preferred since weed competition will be greatly reduced (*30*). Higher seed rates reduce the detrimental effects of weeds (*26*). Seeding in salvaged topsoil will increase competition between seeded species and seed present in the soil (*27*). Higher rainfall can support higher seed rates which may reduce weed competition (*31*). Native grasses compete poorly with forbs, nurse grasses, and weeds (*32, 21*).

In a Kentucky study, (*33*) researchers found that regardless of the seed rate applied (six rates from 0.25 to 3.0 lb/1000 ft^2), there was no significant difference in bermudagrass production after 42 days. After 84 days, there was no difference at all. The seed rate of 3 lb/1000 ft^2 is approximately 6,000 seeds/ft^2. In the study, the researchers applied 50 lb of nitrogen fertilizer to the plots every 30 days.

A study at Louisiana State University (LSU) (*34*) tested seeding ryegrass at rates of 37 to 148 pure live seed (PLS)/ft^2. Researchers found that there was no advantage in total production yield by seeding ryegrass higher than 74 PLS/ ft^2. However, the first-harvest yields were almost three times higher as seeding rates increased from 37 to 148 PLS/ ft^2. Both studies show that high seeding rates lead to high production early but that long-term production is not increased.

These studies contrast long and short-term production goals. High seed rates lead to a more rapid increase in early production but ultimately made no difference in long-term production. The amount of resources available to the plants limits the total production of the stand. Unless depleted soil resources of water or nutrients are replenished, competition will result in some seedlings surviving and some seedlings dying until the population level matches the resource level.

Studies in Montana found that seeding rates above 16 lb/ac improve the competitiveness of intermediate wheatgrass with spotted knapweed, but at rates of 8 lb/ac the wheatgrass did not establish at all (*35*). The study inferred that higher rates provided improved competitiveness.

Dickenson's study conducted in Kansas (*36*) found that high seed density reduced plant species richness and that lower grass seed rates led to significantly more bare ground. The results also noted that the lower rates led to greater species diversity but without any increase in erosion protection. This result would be expected since most early weedy invaders are annuals that have a single stem and a tap-root growth habit.

Researchers in Baraboo, Wisconsin, (*37*) tested seeding densities of 9, 18, 37, and 74 seeds/ft^2. Their results suggested that lower seeding densities may facilitate the establishment of species that are slow to germinate, resulting in greater species diversity but may result in higher weed densities. They also noted that higher seeding densities may create the appearance of quick establishment and fewer weeds but with lower species diversity. In each of the two studies above, increased species diversity may be the result of an increase in invader seeds or germination of seed already in the soil. The studies do not make the distinction.

Another study suggested a strategy for rapid erosion control that includes high percentages of annuals with total seed rates of 30–40 lb/ac (*24*). In a restoration context this method would not promote quick establishment of native perennials. Where routine mowing prevents domination by taller annuals, shorter sod-forming grasses are able to establish and thrive. This growth trend reflected common roadside conditions in Texas.

A visual survey of some existing TxDOT roadsides reveals that few if any (except bermudagrass) of the species seeded at the time of construction survived after only a few years although most sites contain a wide range of diversity of grasses and forbs that were not seeded. This was documented in a 7-mile stretch of State Highway (SH) 47 in Brazos County in May 2006 (*18*) where construction was completed in 2000. The survey team conducted a visual assessment of 12 sites consisting of six randomly selected sections on both sides of the roadway, each measuring 200 ft. The survey found 13 native grass species present, 9 non-native species, 39 native forbs, and 10 non-native forbs. The original seed mix included green sprangletop, bermudagrass, sideoats grama, little bluestem, and Illinois bundleflower. Green sprangletop was not found, bermudagrass was present in all sections, little bluestem and sideoats grama were each present in only one section (not the same one) and Illinois bundleflower was found in six sections.

Another study (*38*) strongly suggests that this invasion trend continues. Texas SH 6 in Robertson County is a long established roadway (over 30 years old). The study included a detailed plant inventory at 13 sites over an 11-mile section and found a total of 14 native grass species, 14 non-native grasses, 78 native forbs, and 15 non-native forbs. The only seeded grass was probably bermudagrass although this assumption cannot be confirmed since the present seed mix was not in effect at the time of construction. The fact that only a few of the seeded varieties persist after seeding suggests that their contribution to vegetation establishment must be questioned. History shows a consistent and widespread invasion by other plants. The most successful seeded species will be those that germinate and grow quickly and are able to compete with early weed competition.

Seeding Components

The research team looked at those areas of practice that deal with the most basic questions of establishing seeded vegetation. The review looked at:

- Species variety.
- Types of species.
- Seeding rates.

Species Variety; Native/Non-Native

Seed mix design considers the area of the project location, desired plant characteristics rainfall, soils, seed availability, costs, and the goals of the project. Often, seed mixes develop through experience over time for large agencies such as TxDOT and include results from years of field experience. In the construction category in Table 1, seed mixes may carry only two or three species but typically six to a dozen. Many of the references reviewed included both warm and cool season grasses particularly in those states with cold winters. Although TxDOT specifies only three mix classifications, temporary cool season, temporary warm season and permanent, much of the literature designates cool and warm season plantings. The warm season is often a permanent seed mixture while the cool season is often a temporary seed mixture. The inconsistent and interchangeable term usage may not direct correlate to TxDOT term usage. Legumes were the most common cool season species. Gulf coast and southwestern states at low elevations may have cool season species as a separate mix.

The goal of TxDOT's seeding program is to establish a viable, permanent ground cover to stabilize and protect the soil from erosion. Multiple species are usually recommended to take advantage of contrasting root growth form (tap-root versus fibrous roots), and to more efficiently fill a wide variety of niches and use varied resources (*35*). The number of seeded varieties in TxDOT's permanent mixes range from two to seven species. These seed mixes are designated as permanent rural or permanent urban on clay or sandy soil. An analysis of seed mixes reviewed in nearby state DOTs found that most follow the same pattern but TxDOT uses a higher proportion of native species.

TxDOT's specified seed mixes are heavily weighted with native species (*2*). The only non-natives in the TxDOT mixes are bermudagrass, weeping lovegrass, and Lehmann's lovegrass.

Many years ago the latter three, imported from South Africa, became known for their easy establishment from seed and were used for livestock grazing or stabilization.

Cool season grasses are generally considered temporary vegetation in Texas since most counties support varieties that are grown in warmer seasons. Northern counties along the Red River and in the Panhandle may support some temporary cool season grasses for longer periods of the year. Legumes are commonly used as temporary cool season additives to mixes. For TxDOT, the temporary cool season mixtures consist of tall fescue, western wheatgrass, wheat, red winter wheat, oats and cereal rye. Foxtail millet is the only specified temporary cool season seed.

Highly diverse seed mixes are more common in restoration and mining reclamation projects. Some of these seed lists may include a higher number of forbs species. In specialized restoration projects, seed may be required that is rare or unavailable in the trades. This usually means special collections and higher costs. The limited availability of specific seeds may be one of the reasons why agencies and companies that must achieve establishment within a specified period of time and at a reasonable cost limit their seed mixes to those species with known availability.
As noted, TxDOT's seed mix contains several native species. The only sod-forming species is the native buffalograss and non-native bermudagrass, except for the Beaumont district, which includes the non-native Bahiagrass.

TxDOT conducted germination studies on its seed mixes as well as enhanced native seed mixes. A seeding study funded by TxDOT (*16*) tested native seed at four sites:

- Odessa with 7 species at 10.5 lb/ac.
- Tulia with 4 species at 5.6 lb/ac.
- Coleman with 5 species at 9.5 lb/ac.
- Lufkin with 5 species at 2.8 lb/ac.

The studies tested mulch versus no mulch installation with none of the plots irrigated. The installations took place in the spring of 1989 and researchers collected data in October 1991. Surprisingly, the tests showed no significant results between mulch and no mulch although later studies did show significant improvements based on varying depths of compost.

The "percent aerial vegetative cover" found in the study provides some interesting insights. Table 3 shows that after two years, only one of the sites had more than 50 percent coverage (Coleman, drill w/mulch). Only the Odessa site showed any significant non-planted species present. Each of the sites had different soil conditions and the study mentioned fertilizer application but no rates were given. Soils were prepared by scarifying but no other amendments were installed.

Table 3. Comparison of Data from Establishment of Grass Mixtures on Roadsides (*16*).

Comparison of Site Data from TX-94\902-6 Research Study				
Site Location	**Seeding Method**	**% Aerial Cover**	**% Non-Planted**	**%Bare Ground**
Coleman	Broadcast w/mulch	33	1	65
	Drill w/mulch	52	1	44
	Broadcast - no mulch	40	2	56
	Drill – no mulch	40	4	55
Lufkin	Broadcast w/mulch	11	5	74
	Drill w/mulch	9	11	72
	Broadcast - no mulch	23	5	63
	Drill – no mulch	26	17	47
Odessa	Broadcast w/mulch	4	34	63
	Drill w/mulch	6	33	63
	Broadcast - no mulch	8	29	63
	Drill – no mulch	10	28	61
Tulia	Broadcast w/mulch	22	7	63
	Drill w/mulch	23	12	62
	Broadcast - no mulch	25	6	61
	Drill – no mulch	26	7	62

The poor results after two years of growth are probably indicative of the difficulties of seed establishment in the arid parts of the state. However, the Lufkin site results contradicted expectations. Lufkin is located in an area of the state with higher rainfall, more lush vegetation and typical invasion by other species. Yet, this site had some of the highest amounts of bare ground. Precipitation for 1989 was 18.64 inches of rainfall with 12.2 inches of that total between May and September. In 1990, a drier year, there was 15.7 inches with 5.8 inches of the total rainfall from May to September. In 1991, more precipitation resulted with 20 inches total, of which 18 inches fell between May and September. Despite these two high precipitation years during the growing seasons of 1989 and 1991, the overall production of these species was judged as very poor. The Lufkin site was the only plot with bermudagrass. Buffalograss was the only other sod-forming species used (Tulia and Coleman).

The standard TxDOT seed mixes were tested in a compost study in 2003 in Lubbock, Karnes, and Falls Counties (*17*). This study examined the effects of compost as an additive, as mulch, and in combination with soil retention blankets. Table 4 shows the vegetative cover results.

Table 4. Treatment Differences for Vegetative Cover.

Treatment Differences for Vegetative Cover with 100 Day Growing Period										
Site & Rainfall (in inches)	**T0**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
Lubbock - 8.14	4.0	22.3	31.7	5.7	5.7	6.7	4.0	7.3	5.7	8.0
Karnes - 2.72	22.2	35.0	47.3	20.7	52.8	28.8	32.8	36.8	29.0	0.8
Falls - 6.41	10.7	2.0	9.5	2.7	0.3	13.5	11.83	1.16	6.7	0.0

The study period was only 100 days so the researchers rated as acceptable the vegetative cover found on the Karnes County site considering that the site had only 2.72 inches of rain. However, the other sites had very poor establishment rates. The authors noted the poor establishment in the Falls County sites but did not speculate on its cause.

In a recently completed study, the Texas Transportation Institute (TTI) (*18*) compared TxDOT's standard seed mix against a specially designed all-native mix, and two levels of increased seed rates. The soils for these study plots, imported from various TxDOT districts—Austin, Corpus Christi, Lufkin, Abilene, San Angelo, and later in the study, Houston—were typical of topsoil for the respective areas and consequently contained a very viable regional seed bank within them. This situation makes direct comparisons with the above two studies more difficult. In the great majority of cases, non-seeded species predominated in the cover estimates and affected the development of the seeded mixes. However, in the comparison of seed mixes, researchers found no significant differences between the standard mix and all-native mix or the standard mix and the first level of the increased rate mix. The higher level increased rate mix did show higher cover in both indoor and outdoor plots.

The studies by Simpkins (*16*) and Fedler et al. (*17*) indicate a poor establishment rate for native seed that is reflected in other studies. The results of the TTI study (*18*) do not provide a fair comparison since researchers did not treat the soil to remove existing vegetation.

Native species are often preferred for roadside use. Cited benefits of native plants include:

- Lower requirement of resources.
- Habitat for native plants and animals.
- Seasonal color displays.
- Provide regional character and identity (*39, 40*).

Although these qualities are all important characteristics of plants in their native environment, their suitability for wide-scale use in the roadside is questionable. Native warm season grasses have low vigor, slow growth, are slow to germinate, and can be easily out-competed by weeds (*24, 41*). Soils in the roadside are highly disturbed and the original soil horizons have usually been obliterated, creating a decidedly non-native and unsuitable growing environment (*42*).

Most native grasses require two full growing seasons to develop significant leafy growth. During this time, soil is often left exposed and subject to erosion. Most native grasses TxDOT uses are bunch-type grasses as opposed to sod-forming species, reducing their effectiveness in erosion control. Native grasses require a stable environment that experiences minimal disturbance or at least substantial intervals between disturbances when they do occur. Mowing and herbicide applications, vehicle runoffs, landowner use, utility-work, and resurfacing operations preclude any form of stability in the roadside.

It is often mentioned that native plant communities would lower mowing and other maintenance costs. TxDOT reduced its mowing schedule over the past 15 years. In most cases, a rural roadside mowing schedule consists of twice per year, considered the minimum to maintain safety. Also, maintenance would likely increase if a native only plant community were to be maintained in a similar manner. Roadsides are very susceptible to invasion of grasses and weeds, both native and non-native. Preventing or removing unwanted invaders would be cost prohibitive if even possible at all.

In their native condition, prairie grasses provide an environmental benefit in the form of habitat, but it is highly questionable that all roadsides can or should be habitat. Habitat must provide burrowing and nesting areas that are stable and undisturbed for at least the time it takes to conceive and rear young, provide a dependable food supply, and not expose its users to serious danger. Unfortunately, roadways are often quite dangerous for animal life.

The value of native plants to roadway construction must be determined by the advantage they provide in mitigating the impact of the roadway on the surrounding environment. Erosion and the potential contamination of surrounding lands are the most significant and urgent environmental impacts posed by roadway construction and management. Considering the nature of native grasses and the slow rate of establishment, their suitability for mitigating these impacts is questionable.

CHAPTER 3 SEEDING RATES

Seeding rates is a controversial subject among various TxDOT districts and divisions. Chapter 6 in TxDOT's *A Guide to Roadside Vegetation Establishment* (*5*), explains the reasoning behind the current district seed rates:

> The saying "If a little does a little good, then a lot will do a lot of good" doesn't always ring true with everything, especially not grass seed. Oftentimes, when designers specify seed mixtures outside of TxDOT's standard specs, more seed gets planted than is necessary. There's only a set, finite amount of food and water available in the seedbeds. The more seed you place on that seedbed, the more competition you create. If you over-apply the seed, not all the plants will die, but they are not going to perform well until natural selection reduces the population to an acceptable level for the soil to support.

Seeding rates vary widely and are dependent upon the goals of the project, budget, timeframe for establishment, types of seed, and other factors. The TxDOT *Guide* discusses rates in two ways: pounds per square acre (lb/ac^2) and seeds per square-foot ($seeds/ft^2$):

- 'Seeds per square foot' calculates mix rates of species based on a prescribed number of seed per square foot of ground surface.
- 'Pounds per square acre' describes the total volume by weight of all seeds combined in a mix.

Small-scale applications (usually of single species installations) are often described in pounds per 1000 ft ($lb/1000\ ft^2$).

> Calculation for PLS makes allowances for the factors that may affect the number of viable seed that makes it to the ground surface. These factors include percent purity, percent germination, and percent dormancy (some references use the term "hard seed" for dormancy). TxDOT uses the most widely used formula for calculating PLS:
>
> **PLS = % Purity x (% Germination + % Dormancy)**

The seeds/ft^2 designation creates seed mixes based on the number of seeds in a pound of each species. The goal is to adjust the weight of each species so that the mix contains approximately the same number of seeds of large and small-seeded varieties. (Rates may also be adjusted for species with high or low germination rates or other unique qualities.)

Seed counts may range from 42,000 seed per pound for buffalograss to over 6,000,000 for Lehmann lovegrass. Specifying the rate by weight alone would greatly favor the establishment of the lovegrass (very small seed) over the buffalograss (very large seed) due to the application of more seed. Once the designer has set volumes-per-species, the cumulative mix is then applied on a volume-per-area of the project (i.e., 22 lb of Mix 'A' per acre).

Comparing seeding rates on a volumes-per-area basis can give very misleading results. Unless the seeds-per-pound of each species is also considered, the actual numbers of seed being applied is unknown. The actual seed number is important because the number of seeds of individual species determines the level of competition for resources that will likely occur between the species after germination. It is theorized that a mixture of native species should compete well among themselves so there would not be any one highly competitive species that grows too high or too large (*40*).

Seed rates in the reviewed references range from 1 seed/ft^2 to 1400 seeds/ft^2 (*43, 29*). Most recommendations tend to fall in the range from 20 to 50 seeds/ft^2. Higher seed rate ranges are usually recommended for difficult sites such as rocky slopes, poor soils, and allowances for loss due to erosion, predation, and any other factor that may reduce the amount of viable seed once it is applied (*44, 45*). Some references recommend high rates in high rainfall areas to take advantage of the water to reduce weed competition (*31*). Research studies have used 300+ seed/ft^2 in grassland restoration studies (*29*). Studies on bermudagrass establishment conducted in Indiana and Kentucky tested rates from 0.25 lb/1000 ft^2 to 3.0 lb/1000 ft^2 (*33*). This equates to an application rate of 500 seeds/ft^2 to 6,000 seeds/ft^2. These rates were for PLS, meaning the actual pounds applied were higher. Most bermudagrass seed will have approximately 2,000,000 seed per pound (not PLS) (*46*).

Most references give a range of recommended seed rates with suggestions for specific site factors. These include rocky ground, slopes, winds, and likely seed predation by animals, length of time until significant precipitation, etc. Recommended rates for broadcast seed are frequently higher than mechanical seeding methods such as drill seeding (*47*).

WHAT IS THE BASIS FOR MOST DOT SEEDING RATES?

The Natural Resources Conservation Service (NRCS) manages the Conservation Reserve Program, whereby farmers are paid for land taken out of production and seeded with permanent grasses. The NRCS developed extensive guidelines for seeding in large acreages which are frequently used as the basis for seeding standards of other agencies such as DOTs. Chapter 6 in TxDOT's *A Guide to Roadside Vegetation Establishment* (*6*), states that "like the seed mixtures, the recommended seeding rates were based upon the NRCS recommendations for 'critical area' seeding."

As mentioned above, the NRCS seeding guidelines include allowances for Critical Area Planting (CAP). CAP is defined as "Establishing permanent vegetation on sites that have or are expected to have high erosion rates, and on sites that have physical, chemical or biological conditions that prevent the establishment of vegetation with normal practices" (*48*). These sites are usually small, measuring less than an acre to a few acres, typically to deal with gully erosion.

This policy allows a seed rate for CAP portions of projects that is double the rate considered to be the minimum for reliable establishment on large areas of range or cropland. Seed rates are published and freely available on-line for zones established in each state. This rate is the maximum amount that the NRCS will pay for as part of a cost-share program for seeding. The rate does not represent a maximum seed rate.

The NRCS seeding rate's goal is to have seeded species represented in the site after 12 months and reasonably full establishment attained at the end of three years (*49*). Earlier NRCS tables for planting rates in Texas (1990) contain the footnote "Rates are based on 20 live seed per square foot in pure stands." Current NRCS Planting rate standards do not contain a reference for seed per area. However, seeding rates in seed/ft^2, range can be calculated from their current charts.

Table 5 contains a sampling of a few of the more common grasses from the NRCS planting rates (*48*).

Table 5. Seed per Square Foot in Sample NRCS Planting Rates.

Seed per Square Foot in Sample NRCS Planting Rates* *Appendix 1, Planting rates for drill or broadcast seeding and sprigging in Texas Zone 5, Sept. 2002				
Species	**Variety**	**NRCS seed rate (lb/ac)**	**Seeds/pound**	**Approx. Seed /ft^2**
Indiangrass	Lometa	4.5	170,000	17
Kleingrass	Selection-75	1.5	525,000	18
Lovegrass	Ermelo	1.5	1,500,000	51
Switchgrass	Alamo	2.0	445,000	20
Sand Bluestem	Elida	6.0	125,000	17
Plains Bristlegrass	-	3.0	293,000	20
Sand Dropseed	-	1.0	1,750,000	40
Green Sprangletop	-	1.7	538,000	20

These differences from older rates are the result of changes made in some of the planting rates in some zones in Texas. The NRCS is moving away from using seed/ft^2 as a benchmark and going instead to "seed ranges" in lb/ac, a practice that mostly applies to the eastern half of the state where rainfall is higher (Zone 4). Using seed rates in lb/ac will reflect a new approach that emphasizes individual site assessment rather than using one set rate. Seeding in optimum conditions may mean less seed is needed while poor conditions may need higher rates (*42*). Leopold considers the new ranges to be conservative even at higher rates and thinks most seed rates should be increased.

Leopold also noted that the NRCS seed rates are designed for range and pasture conditions and would not be directly applicable to meeting TxDOT's timeframe requirements for erosion control on the roadside. He also said that establishing native grasses in poor soil is a "losing battle," Leopold noted that natives are not as hardy as widely claimed. Rather, the native soils of those grasses are very high quality, quite unlike anything we can mimic in the roadside.

Table 6 is a sampling of TxDOT seeding rates to provide a comparison to the findings in the literature. The seed/ft^2 is well above the 20–50 count found in the literature. On the other hand, the rates per acre are much lower than rates found in other DOTs and other agencies. So, if one method is correct, which one is it?

Table 6. Approximate Seed Counts for TxDOT Seed Mixes (*2*).

Approximate Seed Counts of Some TxDOT Seed Mixes* Permanent, Rural, Sandy Soils *Item 164, Seeding for Erosion Control			
District	**Seed Count of Mix**	**Seed per ft^2**	**lb/ac**
Wichita Falls	4,996,400	115	5.7
Tyler	13,126,400	301	13.1
Odessa	3,180,200	73	5.6
Waco	8,061,400	185	5.0
Corpus Christi	9,407,400	216	4.2

As noted earlier, comparing the two different formats can be very misleading. In this case, the comparison offers little insight into a possible rationale even if allowances are made for climate variations. It is also not possible to say that any of these rates are in any way inadequate for some unspecified site. In the end the correct rate will be one that works. The literature is very clear that final seeding rates must be based on site conditions and that published rates are guidelines only, not rules.

Some locales may need to consider diseases affecting seedlings. For instance, high temperatures, humidity, water-logged soils, excessive fertilizer, or an excessive seeding rate can trigger damping-off fungus, found mostly in turf grasses (*50*). High seed rates that produce a dense stand of seedlings can hinder the escape of moisture from the soil surface. In areas of prolonged rain and warm conditions, these conditions favor the growth of fungi that kill seedlings. Areas that have experienced these blight attacks are difficult to re-seed.

SEEDING RATES OF OTHER TRANSPORTATION AGENCIES

The research team canvassed other states to use their seeding rates as a comparison and to find out more about the re-vegetation issues faced and how they are handled. The following summaries also include comments received through interviews with personnel about their seeding and erosion control programs.

Arizona Department of Transportation

Arizona has a variable seed mix based on each zone rather than a copied list for the entire state. The seed mixes vary widely from district to district.

- Were also under a consent decree for environmental actions.
- Prime contractor is co-permittee on the CGP; released after 45 days.
- Permit is transferred to new contractor (Job Order Contracts or JOC) to manage until NOT is submitted.
- High number of mobilizations (17 mobilizations on 400 acre site).
- Rips soil to 12 inch depth – leaves furrows open to catch and store water.
- Uses slow-release fertilizer with reduced amount of soluble fertilizer; breaks down by bacterial action, reduces leaching.
    - ⅓ sulfur-coated urea.
    - ⅓ monoammonium phosphate.
    - ⅓ methyl urea.
- Mostly broadcast seeding on slopes, few flat areas for drill seeding.
- Lots of natives.
- 10 to 20 species, ¼ are grasses, rest is forbs.
- Not concerned with seed/ft^2, two project examples have 24 and 30 lb/ac.
- Seed mixes are based on bio-zone.
- Too many grasses prevent forb development.
- They want shrubs and trees.
- Re-naturalization is the goal.
- Seed by roadway zone.
- Aesthetics is an issue.
- Throw a 25 ft^2 hoop to estimate vegetation cover.
- Have a very strict control over the vegetation establishment process.

Arkansas State Highway and Transportation Department

The Arkansas DOT stated that there were no significant problems associated with seeding establishment.

- DOT pulls CGP. Tried to change that but their Department of Environmental Quality (DEQ) denied it.
- DEQ changing permit…was 75% cover, going to 80% with photo documents required.
- Using less sod…only in swales sometimes.
- Hydroseed or drill…up to the districts.
- Cheaper to reseed than water, second seeding provided in specs, it's a case-by-case thing.

Table 7. Arkansas DOT Seed Mixes and Rates.

Seed Variety Districts 1, 2, 5, 6, and 10	**Seed Rate lb/ac**
March 1-June 15	
Bermuda Grass (Common) unhulled	5
Bermuda Grass (Common) hulled	10
Coreopsis tinctoria	2.5
Lespedeza	10
June 16-August 31	
Bermuda Grass (Common) unhulled	5
Bermuda Grass (Common) hulled	10
Coreopsis tinctoria	2.5
September 1-February 28/29	
Wheat	15
Crimson Clover	20
Bermuda Grass	20
Coreopsis tinctoria	2

California Department of Transportation

The California Department of Transportation has a situation similar to TxDOT's re-vegetation efforts.

- Civil engineers developed new standards but it did not work.
- Led to pilot projects and now standards.
- Still need better vegetation techniques for stabilization.
- Looking to TxDOT for possible solutions.
- Contractors are on the permit.
- Problem with invasive weeds after installation.
- Districts do their own thing but standards for methodologies are set by Division.

- Division supplies base seed list to choose from - seed rates set by Districts.
- District Landscape Architects (LA) are responsible for design and specification of re-vegetation projects.
- District Biologist provides LAs with seed list – arguments occur here.
- LA ability are highly variable – no training program.
- Very big into salvaging topsoil – they call it duff.
- Use a wide variety of grasses and forbs.
- Stopped seeding shrubs due to length of time of establishment.

Florida Department of Transportation

Unlike many other DOTs, the Florida DOT states that natives are "not a big thing." They use some wildflowers in the re-vegetation process.

- Contractor gets the CGP.
- Native grass is not a big thing; using some wildflowers.
- Biggest problem is hard, short rains.
- Working on a designer's manual.
- State Department of Environmental Protection (DEP) contracts out inspection to consultants.
- DEP set standards…pretty easy to follow.

Table 8. Florida DOT Seed Mixes and Rates.

Seed	Seed Rate lb/ac			
	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Aeschynomene	•	•	4	•
Pensacola Bahiagrass	40	40	40	40
Common Bermudagrass	10	10	10	10
Arrowleaf Clover	4	•	•	•
Crimson Clover	10	•	•	•
Hairy Indigo	•	4	•	4
Browntop Millet	•	•	10	10
Ryegrass	10	10	•	•

Oklahoma Department of Transportation

As confirmed by many other DOTs, the Oklahoma DOT stated that "seeding is not a problem where soil is good and rain is adequate!"

- Uses 30 year old seed list, has a list for each county.
- Uses different mix everywhere.
- No one follows up on seeding in the field.
- No engineer in charge of erosion control…follows (DEQ) standards.
- During plan review they ask the district what they want; plans come from central office.
- Most jobs are too small for seeding…most projects use solid sod.

Table 9. Oklahoma DOT Seed Mixes and Rates.

Seed	Seed Rate lb/ac (Average Project)
Warm Season	
Little bluestem	8–12
Sideoats grama	6–8
Blue Grama	6
Buffalograss	6–8
Bermudagrass	4
	30-36 lb
Cool Season	
Ryegrass	30
Crimson Clover	12
Wheat (alone)	100
Fescue	20–30

New Mexico Department of Transportation

New Mexico does not have a prescribed mix but requires a list to be developed as part of the re-vegetation/erosion control plans.

- Takes a long time due to lack of rain but not much there to begin with.
- Video documentation of project prior to construction.
- Use dormant seeding (seed sown during vegetation's dormant season so available when rainfall arrives) of cool season species.
- Tried compost - did not help vegetation establishment but did help hold soil in place.

- Use compost socks and wattles.
- New Mexico Environmental is state regulatory agency and is very involved in DOT projects.
- The DOT co-permits with contractor.
- Successful getting 70 percent cover and now submit for finals electronically.
- Going back to seeding with compost and mulch.
- Require certification in erosion control.

CONCLUSION FOR SEEDING RATES

It is clear from the above examples that selecting a "correct" seeding rate can be very complex and involves considering variables that are completely unpredictable. There are three possible results from the seeding rate decision:

- The seed rate is too low, in which inadequate cover is established resulting in erosion or the need for another seeding operation.
- The seed rate is too high, resulting in higher seed costs and possible decline in viable seedlings in the post-establishment phase.
- The seed rate is just right for the conditions.

There are two goals in seed establishment on the roadside. The first is to meet the NOT regulatory requirements for vegetative cover and obtain contract closure on the project. The second is to match the vegetative cover to the "level of constant yield" of the specific site to avoid spending too much or avoid getting too little vegetation established. Figure 1 shows the relationship of cost, time, and vegetation cover. The literature shows:

- High seed rates will lead to a period of cover reduction (possibly below the 70 percent cover figure, but this is not proven).
- A lower, optimum seed rate will take a longer (but acceptable) period of time to reach the 70 percent cover.
- Too little seed will be below the 70 percent cover requirement (not shown).

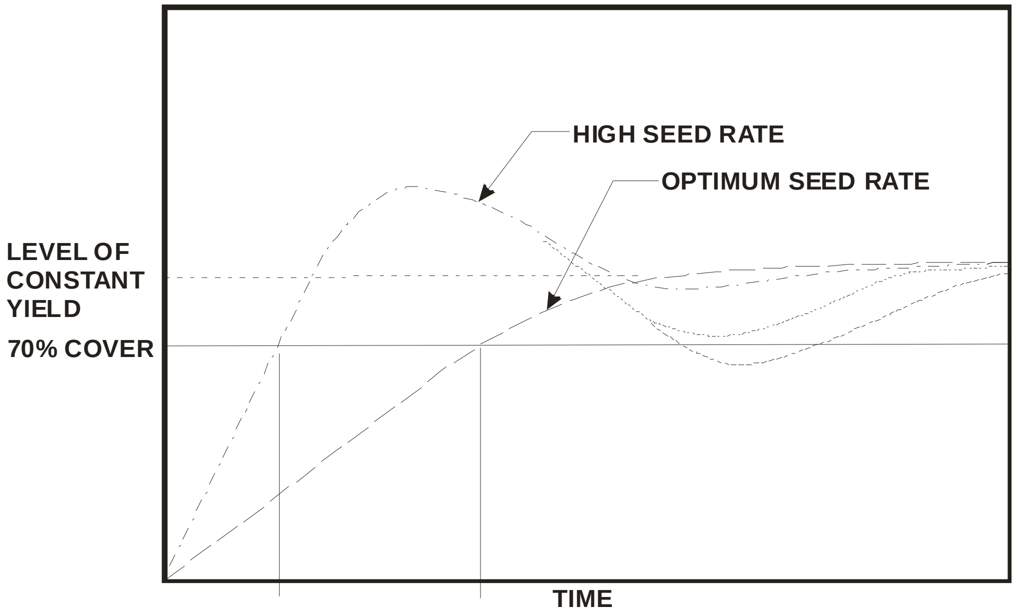


Figure 1. Comparison of Possible Effects of Seeding Rates over Time.

The graph of these relationships points out the tradeoffs and the decisions that designers must weigh. It also points out the problem associated with making the 'right' choices in seeding rates. Some of the questions are:

- Will the higher seed rate lead to a ‘crash’ later and will that crash results in less than 70 percent cover?
- How prohibitive is the cost differential of the higher seed rate?
- Will higher seed rates lead to a significant time saving and will the time savings actually result in lower costs?

Answers to these questions depend on the many variables previously discussed: soil, nutrients, moisture, species, seed bank, after-care, installation practices, time of year, competition, germination rates, etc. It boils down to the question of the value of time versus the present value of money versus future time and money at risk. These are site-dependent issues and the literature offers no specific guidance on how to adjust seed rates for these as a group and only marginally in the case of competition (as with weed species).

CHAPTER 4 ASSESSMENT OF TXDOT PRACTICE

The research team conducted an assessment of seeding practices and problems experienced in TxDOT districts. The problem of vegetation establishment was approached as part of the larger context of erosion control in roadway construction projects and the requirements of meeting SW3P requirements. The assessment process assumed that a long list of requested information would be tedious to complete and would likely miss important information. This process was intended to elicit responses that were not pre-determined. The researchers accomplished this objective by requesting information through personal phone interviews and using open-ended questions rather than Yes-or-No responses. The staff members were allowed to volunteer information relevant to their experience. Researchers documented the district, name, position, and contact information and collated responses without reference to the individual's name.

GATHERING INFORMATION

The research team used a list of questions to provide as a prompt for discussion of issues rather than specific quantified answers. The discussion was allowed to target the most critical or problematic issues. The respondents were also encouraged to propose solutions they felt would help deal with problems they might be experiencing. The questions are listed below.

- How would you rate the adequacy of training your staff receives in erosion and sediment control (E&SC) practices?
- Is there any aspect of E&SC implementation that causes a disproportionate degree of headaches?
- Does your district have a set of BMPs used most often on projects?
- Based on your experience, do the contractor's representatives have sufficient or adequate expertise in storm water management and vegetation establishment?
- What method do you use to determine if the 70 percent vegetated cover requirement has been met?
- Are there instances where the minimum vegetation requirement is not met and receiving the Notice of Termination delayed? Why?

- Which type of vegetation establishment method has been most successful for you? (broadcast seeding, drill seeding, block sod, etc.)
- Does your area use the standard seed species and rates as is or do you modify it as needed?
- Which grass species have been most successful? Which has been least successful?
- Do you closely follow the seeding dates for the permanent and temporary seed mixes?
- Can you or your inspectors identify the standard seed varieties once they have established?
- How quickly do you usually get coverage with: Cool season mix? Warm season mix?
- Who determines which seed type will be installed on a project?
- Do you use compost additives as mulches or to improve soils?
- What suggestions would you make to improve the process of getting permanent vegetation established at the end of a construction project?
- Miscellaneous.
- Contractors.

TXDOT DISTRICT RESPONSES TO REQUESTED INFORMATION

Because of the open-ended format, there were many varied responses. This type of format does not lend itself to statistical explanation. The research team felt this was not necessary. If a particular issue was identified as a problem by only a few, it should not necessarily lessen the importance of that issue. The identified issue is still a problem and should be expressed even if only one or two instances were found. This approach is valid due to the great variance in climate, soils, etc. across the state. After a number of discussions, the research team began finding recurring issues and similar impressions regarding problems and potential solutions. These findings are summarized in the following list of comments distilled from the entire group and representing the range of responses. Some items were mentioned only once or are unique comments. Others represent many responses, at least in general, if not specific conditions. Some of the following are phrased as observations by the researchers; some are excerpted as comments from the respondents.

Respondent Comments, Observations, and Excerpts

- Contractor compliance is generally poor *(referring to upkeep of construction SW3P issues and vegetation establishment).*
- Contractors underbid E&SC items to get contracts *(SW3P contracts part of construction projects).*
- Contractors are usually held until NOT in high-rainfall districts.
- Contractors are usually released from NOT in arid districts.
- Would like to have more and better tools for erosion BMPs.
- Subcontractors are generally poorly trained, too far away, overbooked *(specifically SW3P contractors as part of roadway construction projects).*
- Need to get the industry better educated *(referring to erosion control and vegetation establishment).*
- Most districts use Item 164 standards…mostly. Some "tweaking" is common. *(lots of equivocation on this question).*
- Consultants not familiar with the area don't use appropriate BMPs and they have to change-order things later in the project.
- Empower contractors to document and self-inspect (the site) with TxDOT oversight.
- Inspectors do not know enough about vegetation establishment – need more training. Training should be the same for inspector and contractor.
- Inspection is highly variable in terms of on-site control.
- Contractors make changes to seed mix without telling inspector.
- Seeding BMPs are often copied from project to project without field analysis.
- Seed costs are a minor part of the seeding process.
- Soils tests are after the bid and may call for more fertilizer than in the bid.
- Asphalt emulsion works very well but many feel uncomfortable using it due to public perception.
- The 70 percent vegetative cover is visually estimated.
    - Problems in vegetation seeding include seeding in summer, and seeding during droughts.
- Most seeding breakdowns appear to occur at point of installation.

- Seeding rates may be too high for arid area – lighter seed rate may be more effective.
- Topsoil salvage is the most effective method for getting grass established.
- Topsoil salvage is not suited to long projects with narrow right-of-way; too expensive to stockpile and then truck back to sites.
- Native seed bed is the best tool – would like to see more options for natives.
- Drill-seed and straw or hay mulch seems to be the most successful seeding method.
- Mixing of temporary cool and permanent seed is pretty common.
- Compost is expensive, mostly due to shipping costs – few or no close sources.
- Compost quality is getting poor – not fully composted.
- We would like to have more options for temporary cool season seeding.
- Most arid districts say watering is counter-productive and enormously expensive.
- Soil changes within a project require different mixes.
- Some contractors feel the seed rate is too low.
- Some contractors feel the seed rate is just fine.
- "Used to have a district mix but using Division now. Major grass was bermuda/Bahia but now is bermuda/lovegrass. Waiting to see results."
- Complaints about costs center on the specific line-item cost rather than later costs or long-term costs that may affect the maintenance sections.
- The use of temporary warm season annuals such as millet and temporary cool season annuals such as ryegrass is very popular with the engineers since they come up so quick. Also, they can get the millet to come up in the summer when bermudagrass will not germinate.
- A number of areas have at least some experience with compost and each complains about its cost. In the next sentence though, they say they usually get great seeding results when they use it.
- A few commented that the quality of compost has become a problem as tests have rejected quite a few batches. They were cited as being "too green." Most have used the blended-in-place as a soil conditioner and like the results but seem reluctant to use it in large areas due to costs.

Discussion of General Re-Vegetation Practices and Problems

No single cause was determined to be the failing component of vegetation coverage. This seems to indicate that the interaction of many variables may be at work. Items identified that have the greatest impact on the success of reaching the vegetative coverage necessary to meet the TPDES requirements are: watering, fertilization, erosion, compaction, and season (temperature and precipitation). A causal loop diagram was constructed (Figure 2) in an attempt to organize and analyze relationships between the items. The items are connected by directional arrows which represents how one variable affects another. A "+" near the arrow head indicates the attached item causes an increase in the subsequent item. A "–" indicates the opposite. For example, increasing compaction will increase overland flow which increases erosion which decreases the potential for vegetation establishment. However, adding compost or SRBs to the compacted topsoil decreases the potential for erosion. It becomes clear that none of these items are independent of another with respect to vegetation establishment. All of these variables are changing over time. The items on the left side of the diagram are ones that can be controlled and that are specified by the design plans. However, temperature and precipitation are natural variables of climate.

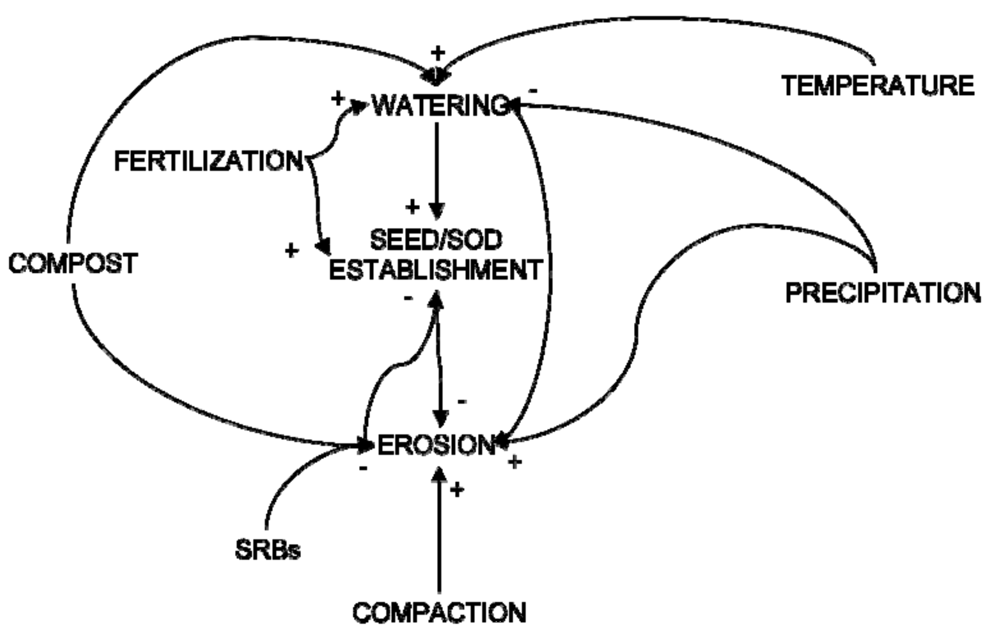


Figure 2. Vegetation Establishment Causal Loop Diagram.

The eco-region and precipitation maps (Figures 3–5) show that the climate is not constant across the state of Texas. The regional variability of temperature and precipitation is likely responsible for the lack of one identifying problem with vegetation establishment across the state.

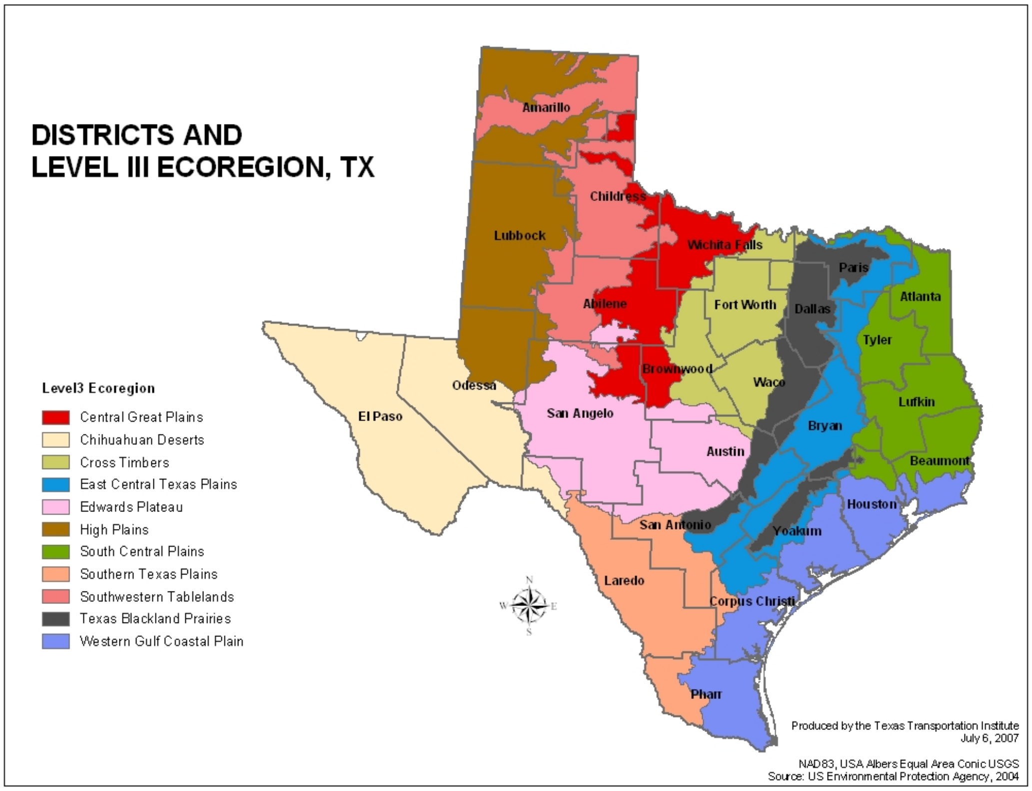


Figure 3. TxDOT Districts with Ecoregions (*51*).

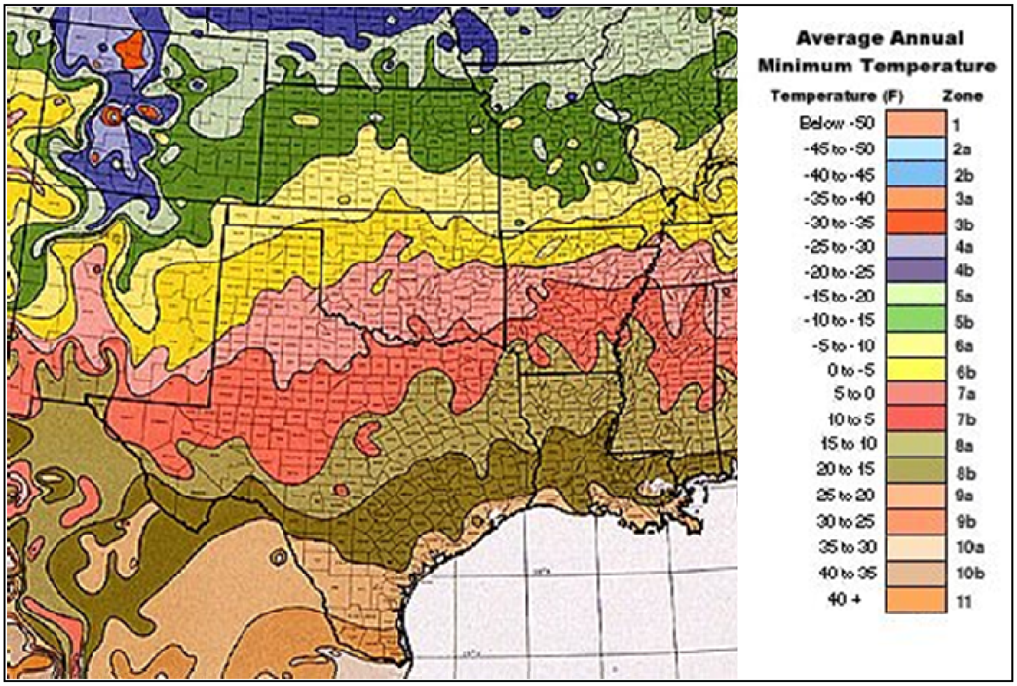


Figure 4. Average Annual Minimum Temperatures (*52*).

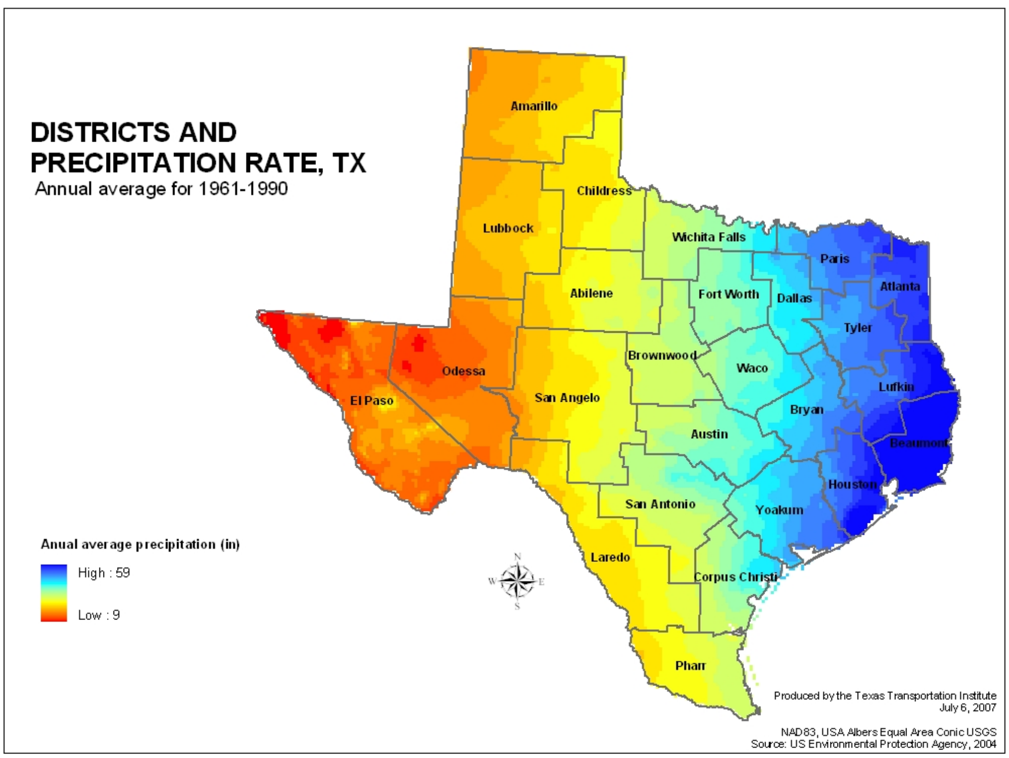


Figure 5. TxDOT Districts and Precipitation Rates (*53*).

TxDOT has the information necessary for designers, consultants, contractors and inspectors involved in the re-vegetation process. The problem lies in the lack of communication and dissemination of existing information/manuals to the personnel involved. Information is located in various documents. Numerous people from consultants to TxDOT staff develop construction site plans. The items pertaining to the vegetation establishment process are listed in the design plans as pay items.

The designer selects specific items for the location and season in which the work is scheduled (Figure 6). This process includes selecting grass mixes for the district and season appropriate according to the TxDOT specifications and the seed application method best suited for the soil and slopes of the site. Even with the correct seed and the appropriate planting methods that follow the published specifications, adequate coverage usually takes more than one growing season in the western portion of the state. In the Texas Panhandle, vegetative watering is performed by water truck and during dry conditions; however, this type of watering is severely inadequate for seed germination. Area plans often include specifications requiring drill seeding and watering only after a rainfall event in order to achieve and maintain adequate soil moisture for seed germination.

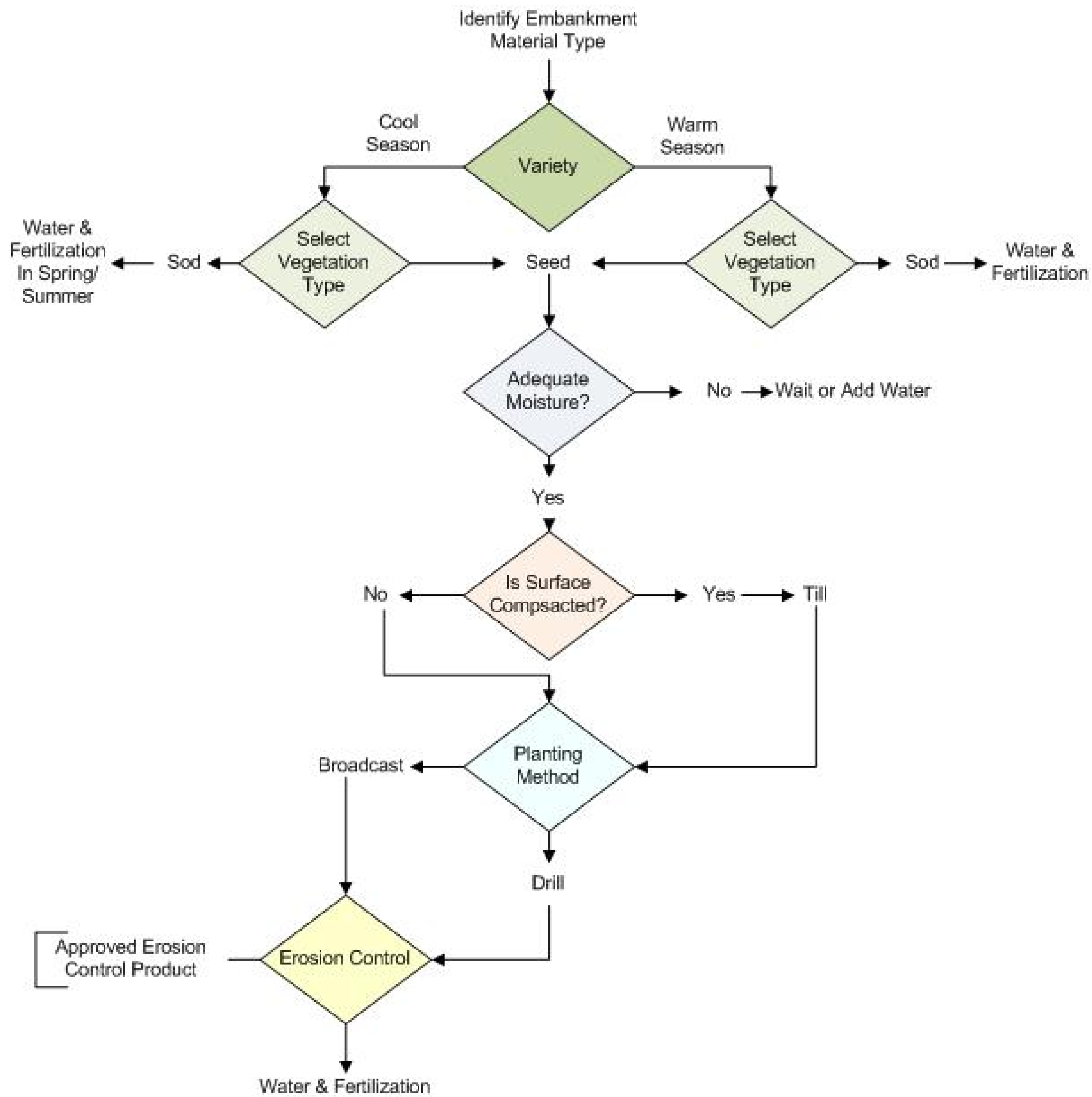


Figure 6. Basic Vegetation Establishment Decision Tree.

According to the TxDOT staff, it has been difficult to procure reliable contractors that can successfully follow and accomplish the re-vegetation guidelines. Local contractors who perform construction and maintenance operations for TxDOT are often the same contractors who perform re-vegetation procedures. Contractors are reluctant to perform re-vegetation procedures in a piecewise fashion as segments of the highways are completed. Many of the crews that are responsible for re-vegetation are also responsible for road construction. These workers oftentimes work on hot patch crews; hot patching is highly profitable for the contractors so it receives top priority when available. There have been notably good contractors who have performed adequate re-vegetation work. However, these contractors are reluctant to travel long distances for the relatively small amounts of work.

Most engineers consider it difficult to evaluate the current re-vegetation process because it is not being implemented as designed. The Vegetation Management Section of the Maintenance Division notes this as a principal issue. Interviews of contractors support this insight. Contractors complained of highly variable expertise and performance of TxDOT inspectors that frequently compromised their work. Some respondents suggested that many of the problems associated with poor vegetation establishment could be blamed on poor execution of the seeding operation.

The lack of cooperation and coordination between construction and re-vegetation activities has also been a major obstacle. Some respondents suggest that there should be more soil and plant science education for the workers performing re-vegetation duties. However; others feel that this is not necessary, they just need to perform the assigned duties as specified. Most of the TxDOT offices do not hold the contractors responsible for re-vegetation establishment after they have made an attempt at following the re-vegetation guidelines and pay items. Engineers have indicated that a region-based decision tree would be a useful tool for designing and implementing future re-vegetation plans. However, a region-based approach would require adoption of new re-vegetation standards for the proposed districts.

The regulatory requirement of "a uniform (i.e., evenly distributed, without large bare areas) perennial vegetative cover with a density of at least 70 percent of the native background vegetative cover" rule may be too subjective (it is often a visual observation) when compared to the adjacent undisturbed vegetation and it may not be applicable in areas where the surrounding area is cropland. The respondents indicated that most contractors are familiar with the BMPs on the bid sheets, but most do not respect the items due to the relatively small percentage (1 percent or less) of the total payout items. The lack of respect for the BMPs and the SW3P is the most expressed concern regarding contractors not being held liable for obtaining and maintaining the SW3P requirements.

Observations Regarding the Notice of Termination

The prime contractors will sometimes handle all the E&SC work with their own forces on smaller projects, but on larger projects, they will typically use sub-contractors. Most of these sub-contractors are DBEs (Disadvantaged Business Enterprises). The prime contractors like this because federally funded contracts require using DBEs when possible.

This type of work is labor-intensive and does not require extensive capital for a new start-up company. Consequently, the experience level is often very low and training may be non-existent. These sub-contractors will also perform the seeding or whatever type of vegetation establishment is required. Again, training is minimal so whatever is stated in the plans is the extent of their knowledge. However, this is not always the case. Some sub-contractors that have been around for a while do a pretty good job, but many respondents say this area is a problem. On very large projects, the prime contractor may hire an 'environmental company' to do the work. In these cases, the skill level can be very high.

There is a wide diversity of approaches to dealing with the issue of attaining sufficient stand of vegetation to warrant a NOT, i.e., 70 percent coverage. Climate plays a partial role. East Texas districts may be more likely to release a contractor without the requisite vegetation coverage due to adequate regional rainfall which facilitates rapid vegetation establishment. Conversely, even with adequate rainfall, some feel the contractor should be held until the 70 percent is reached because there is adequate rainfall and grass grows quickly.

Districts west of I-35 stated that it takes more than one growing season to get permanent vegetation established to the required 70 percent and will not hold the contractor that long. The district may release the contractor but hold the NOT open until the 70 percent is reached and the final paperwork submitted. This means that TxDOT assumes responsibility for maintenance of any BMPs and must continue the necessary inspections. One respondent said the district will keep the contractor no matter how long it takes, but suspend time on the contract and still require the contractor to repair the BMPs. The one common suggestion was to have the contractor as a co-permittee to ensure more responsible treatment of the issues that could result in serious problems for TxDOT if mishandled. TxDOT is currently examining the ramifications of co-permitting projects.

In general, the gathered information found that the attainment of the NOT was not considered problematic by the districts. However, for some districts, the NOT is a major issue. One TxDOT engineer said they routinely release the contractor once the final BMPs are in place. He noted: "It's our project and we're going to get the responsibility eventually anyway."

CONCLUSIONS FROM THE REQUEST FOR INFORMATION COMMENTS

Most districts stated that what they do is working. However, some districts often modify the established standards to meet specific needs. They would generally like to have a wide choice of alternatives for vegetation establishment.

- Districts in arid regions have the most problems, primarily associated with the time it takes to establish vegetation.
- All districts feel there is a lack of expertise at the point of installation and other places in the sequence. Inspector and contractor training are needed. This applies to both E&SC and to vegetation establishment.
- The contractor does not consider vegetation establishment important. (This will probably not change until permitting requirements change).
- Districts are experimenting on their own to expand their options.
- Most districts have little quick access to expert on-site decision-making support.
- Although available, training programs (for TxDOT inspectors) are not explicitly required and are on a per request basis.
- The present seed list, rates, and dates are too narrow for the diversity of environments and communities in Texas.
- Practices and specifications differ from district to district and sometimes between area offices within the same district.
- Most everyone seems to be doing whatever works for the situation.
- The majority of districts do not consider obtaining the NOT to be a significant problem.

CHAPTER 5 VEGETATION ESTABLISHMENT TOOLS

There are three additional deliverables from the research conducted for this project that were not part of the original scope. These deliverables were developed over the course of the project with consultation from the project panel. The researchers recognized that the gaps in the vegetation establishment process are communication among those responsible for the design and implementation of the project plans. To assist in meeting the TxDOT goals of regulatory compliance and better communication, the following tools were developed:

- Vegetation Establishment Guidance for Decisions Assistance Tool (VEGDAT).
- Roadside Vegetation Establishment Quick Reference Field Guide.
- Example District Standard Sheet for Vegetation Establishment.

VEGETATION ESTABLISHMENT DESIGN DECISION ASSISTANCE TOOL

The Vegetation Establishment Guidance for Decisions Assistance Tool (VEGDAT) was devised to provide the designer (unfamiliar to the re-vegetation process, i.e., Engineer-in-Training) with a concise method of directly accessing pertinent information from numerous existing TxDOT documents vital to design decisions. VEGDAT's purpose is to:

- Provide tools for better decision-making for the vegetation establishment process.
- Promote greater efficiency and coordination among TxDOT staff, contractors and consultants.
- Provide information regarding the Items generally associated with vegetation establishment.
- Facilitate meeting the TPDES requirements for percent vegetative coverage needed in order to file the NOT to release the contractor's obligations for the project.

VEGDAT was created to try to simplify and facilitate the design decision process. It consists of a series of decision trees generated to acquaint the user with the vegetation establishment process. The decision trees consist of the Items most frequently employed in post-construction re-vegetation activities to meet the TPDES NOT requirements. VEGDAT is self-contained on a CD with minimal external links to the internet.

Prompts direct the user to vital bid item related information interconnected via active links to documents and the Internet. Moving the cursor over the Items listed prompts a link to a decision tree or other resource. The individual decision trees contain links to other information as seen when the cursor moves over the boxes. This information includes excerpts from various existing TxDOT manuals and documents. This concept is to direct the user to a specific piece of information pertaining directly to whatever is being queried in the decision tree. For example, Figure 7 shows the Item 160 Topsoil Decision Tree. From this, the user can link to information such as associated Items, excerpts from *A Guide to Roadside Vegetation Establishment* regarding topsoil stockpiling, seedbed preparation, etc.

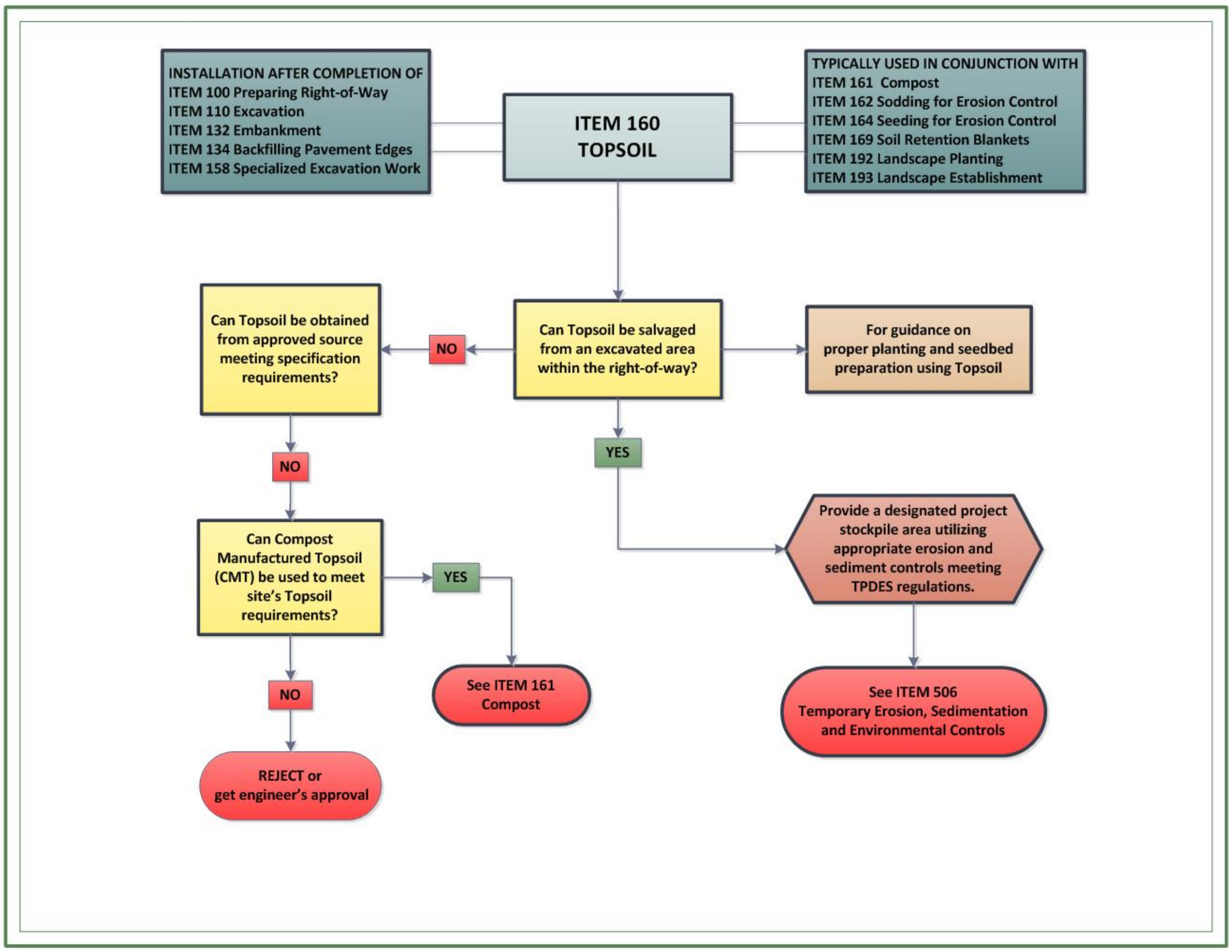


Figure 7. VEGDAT Item 160 Topsoil Decision Tree.

The research team developed VEGDAT decision trees for the following:

- Item 160 Topsoil.
- Item 161 Compost.

- Item 162 Sodding for Erosion Control.
- Item 164 Seeding for Erosion Control.
- Item 166 Fertilizer.
- Item 168 Vegetative Watering.
- Item 169 Soil Retention Blankets.
- Item 180 Wildflower Seeding.

Information Sheets were also developed to help supplement or clarify the TxDOT specifications for the specific Items and are linked into VEGDAT. These Sheets attempt to bridge or fill in the blanks where necessary. The VEGDAT individual information sheets for the specific Items contained in the decision trees are:

- Item 134 Backfilling at Pavement Edges.
- Item 161 Compost.
- Item 164 Seeding for Erosion Control - Crimped Straw.
- Item 164 Seeding for Erosion Control - Vertical Tracking.
- Item 169 Soil Retention Blankets.
- Item 314 Emulsified Asphalt Treatment.

The Information Sheets were prepared to fill in the gaps in information between the specification and implementation on the roadside. They generally consist of the following categories:

- Related TxDOT specifications, special specifications and/or special provisions.
- TxDOT related bid items.
- TxDOT installation details.
- Description.
- When and how to use.
- Considerations.
- Inspection and maintenance.
- Graphics, such as the one shown in Figure 8.

The Items most generally associated with the vegetation establishment process include and are linked in the same manner:

- Item 100 Preparing Right-of-Way.
- Item 110 Excavation.
- Item 132 Embankment.
- Item 134 Backfilling Pavement Edges.
- Item 158 Specialized Excavation Work.
- Item 160 Topsoil.
- Item 161 Compost.
- Item 162 Sodding for Erosion Control.
- Item 164 Seeding for Erosion Control.
- Item 166 Fertilizer.
- Item 168 Vegetative Watering.
- Item 169 Soil Retention Blankets.
- Item 180 Wildflower Seeding.
- Item 192 Landscape Planting.
- Item 193 Landscape Establishment.
- Item 204 Sprinkling.
- Item 300 Asphalt, Oils,, and Emulsions.
- Item 314 Emulsified Asphalt Treatment.
- Item 506 Temporary Erosion, Sedimentation and Environmental Controls.
- SS 1001 Compost.
- SS 1009 Landscape Soil Amendment.
- SS 1011 Compost-Mulch Filter Berms.
- SS 5049 Biodegradable Erosion Control Log.

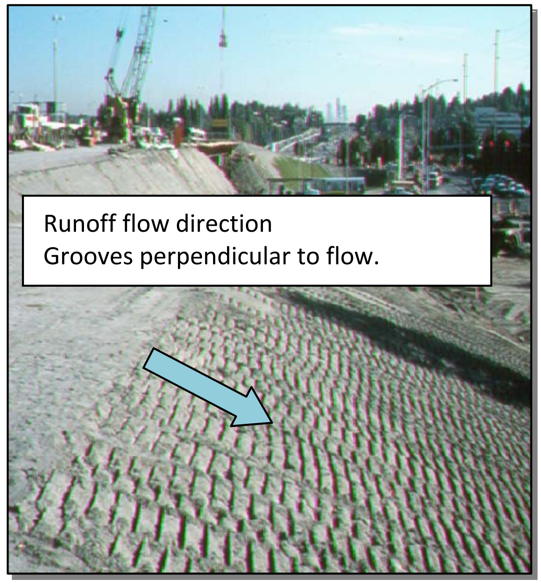


Figure 8. SP 164-004 Vertical Tracking.

Links to the sources for VEGDAT include the following documents:

- *TPDES General Permit No. TRX150000.*
- *TxDOT Guide to Roadside Vegetation Establishment.*
- *TxDOT Storm Water Management Guidelines for Construction Activities.*

- *TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.*
- *TxDOT Storm Water Field Inspector's Guide.*
- *TxDOT Hydraulic Design Manual.*
- *0-5748 Water Retention Techniques for Vegetation Establishment in TxDOT West Texas Districts.*

ROADSIDE VEGETATION ESTABLISHMENT QUICK REFERENCE FIELD GUIDE

Researchers developed the Roadside Vegetation Establishment Quick Reference Field Guide to offer personnel a simpler method of accessing the vast quantity of information in existing TxDOT manuals and documents. The guide references four main documents:

- *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.*
- *A Guide to Roadside Vegetation Establishment.*
- *Storm Water Management Guidelines for Construction Activities.*
- *Inspector Development Program.*

The purpose of this document is to:

- Facilitate meeting the TPDES requirements for percent vegetative coverage required for filing the NOT to release the contractor's obligations for the project.
- Provide tools to better manage the vegetation establishment process.
- Promote greater efficiency and coordination among TxDOT staff, contractors and inspectors.
- Facilitate on-site decision-making.
- Provide information regarding the pay items generally associated with vegetation establishment.

The guide contains concise information on these topics and pay items as they relate to vegetation establishment on the roadside:

- SW3P environmental inspector requirements.
- Planting procedure for construction operations.

- Item 5 Control of the Work.
- Item 100 Preparing Right of Way.
- Item 110 Excavation.
- Item 134 Backfilling Pavement Edges.
- Item 160 Topsoil.
- Item 161 Compost.
- Item 162 Sodding for Erosion Control.
- Item 164 Seeding for Erosion Control.
- Pure live seed calculations.
- 164.3.A. Broadcast Seeding.
- 164.3.C. Cellulose Fiber Mulch.
- SP 164-004 Bonded Fiber Matrix.
- 164.3. Drill Seeding.
- Drill seeding equipment calibration.
- SP 164-04 Vertical Tracking.
- Item 166 Fertilizer.
- Item 169 Soil Retention Blankets.
- Item 314 Emulsified Asphalt Treatment.
- Website and references.

The guide is a companion reference to the project plans, specifications and general notes. For more information regarding project specifications and construction related matters, consult the project plans and specifications. The designer should always be certain to check for district specific information regarding vegetation establishment.

EXAMPLE DISTRICT STANDARD SHEET FOR VEGETATION ESTABLISHMENT

Over the course of this project there was much discussion regarding the process of establishing vegetation on the roadside. The key issues were:

- Variance of each district's practices and handling of the process.
- Ensuring that all steps of the process have been completed (pay items).

- Getting the available information from the designer to the contractor in a concise format that ensures compliance to the extent possible.

Standard sheets have long been part of plan sets for TxDOT. Houston and other districts have developed standard sheets that are part of each project that requires re-vegetation. The applicable pay items, process and accompanying details are included and these can be adapted for each district's specific needs. The example sheet can be found as a link in the VEGDAT and is presented in as an example of how this concept can be incorporated into the process. One of the key issues with the standard sheet for vegetation establishment is that each pay item and associated requirements are designated on the sheet. The example includes a sequence of work as well.

CHAPTER 6 VEGETATION ESTABLISHMENT STUDIES

One area of Texas that continues to be problematic for vegetation establishment is the semi-arid and arid area of west Texas. Establishing permanent vegetative cover to meet regulatory requirements often takes more than one growing season, usually 2 to 3 years. Inconsistent and sparse rainfall coupled with poor soils, excessive heat, and constant wind does not make an environment conducive to growing grass! One district representative commented that silt fences were more likely to be blown down by wind rather than destroyed by sediment or water. Current re-vegetation practices in the Panhandle are producing unreliable results. Contractors are inconsistent in methods and timing to re-establish vegetation on construction sites.

The experimental plots followed the TxDOT specification for Item 164 Seeding for Erosion Control. Four seeding mixtures, identified by soil type and district, (TxDOT recommended seed mixtures) were used. The only deviation from the specification consisted of:

- Planting cool season temporary and permanent (referred to as warm season) together.
- Planting cool season temporary in the fall, terminating the following spring, and then planting permanent into the residue.

Researchers chose four experimental sites in the west Texas area located in Adrian, Amarillo, Canyon, and Lelia Lake. These sites were planted in November 2008, February 2009, and May 2009. Percent cover and species composition were determined along transects in May, June, and August, 2009 and June 2010. Seed mixtures had no effect on percent cover. However, the addition of compost significantly increased vegetative cover to 80 percent vegetative cover or above at all locations.

MATERIALS AND METHODS

Experiment Site Locations

There were four experiment sites across the Texas Panhandle: 12 miles west of Adrian (35°14′22.10″N 102°49′48.96″W), west Amarillo (35°12′21.95″N 101°56′15.48″W), 4 miles south of Canyon (34°54′42.03″N 101°55′27.39″W, and 2 miles north of Lelia Lake (34°52′51.16″N 100°43′24.65″W) (Figure 9) (*54*). Precipitation varied among locations. During

February 2009 to May 2010 the Adrian location had 11.1 inches of precipitation. The Amarillo site had 17.1 inches, the Canyon site measured 5.8 inches for 6 months, and the Lelia Lake site had 25 inches of precipitation from February 2009 to May 2010 (Figure 10).

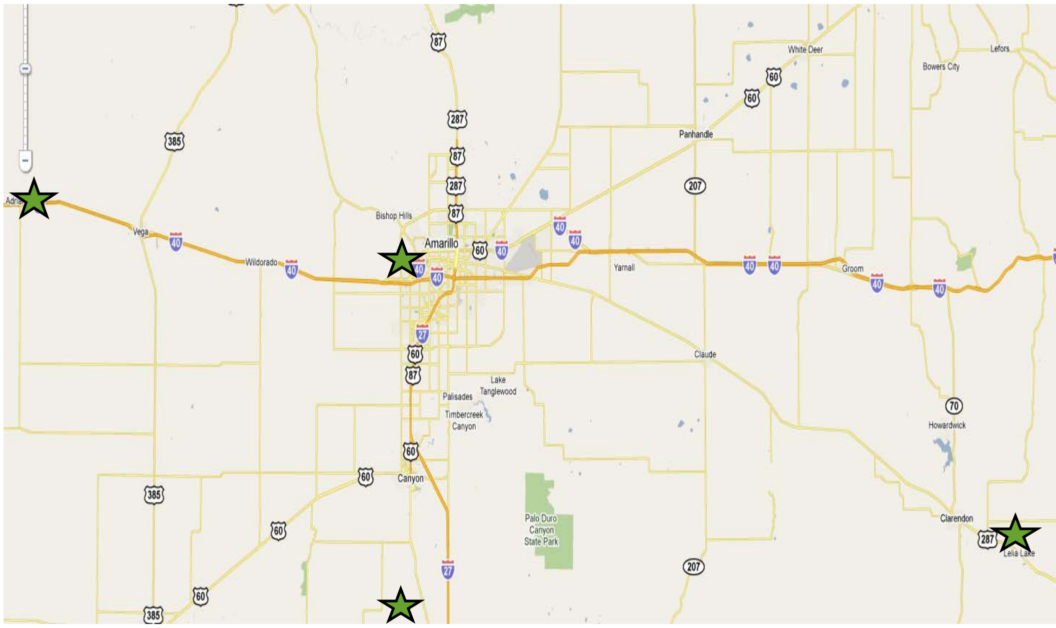


Figure 9. Location of West Texas Demonstration Plots.

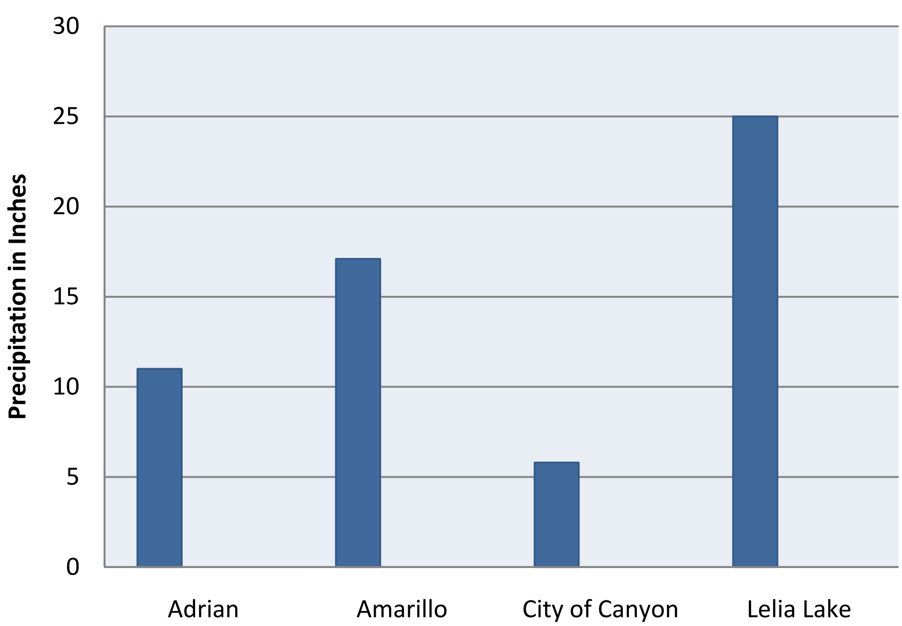


Figure 10. Precipitation February 2009 through May 2010.

Because the Canyon site had the least amount of precipitation, weather data from The City of Canyon and West Texas A&M University Feedlot were obtained to compare precipitation. The City of Canyon had 21.2 inches, and The West Texas A&M University Feedlot has 9.2 inches of precipitation from February 2009 to May 2010 in comparison to the Canyon site which had 5.8 inches of precipitation. These results indicate that the precipitation monitor may have suffered some damage because no readings were made after July 30, 2009. The Appendix shows all data from the sites.

The research team collected data regarding the average ambient and soil temperature data from February 2009 to May 2010 at all of the sites except the Amarillo plots. The Amarillo site data were recorded only during February 2009 due to rodent damaged wiring shortly after weather station placement at the site. Researchers measured the ambient temperature from February 2009 through September 2009. Because of damage to the temperature monitors, researchers used weather data from nearby Bushland Agricultural Research Service (see the appendix). Table 10 shows the site specific information.

Table 10. Experimental Sites Specifics.

Plot Location	Plot Size (Acres)	Slope/ Terrain	Slope Aspect	Soils	Average Ambient Temperature	Average Soil Temperature at 3.15 inch
Adrian bordered east bound lane of I-40	10.6	3% rocky	North	sandy clay loam 42.6% sand 25% silt 32.4% clay	55.2°F	56.8°F
Amarillo along north and south bound lanes of Soncy Road, north of SW 9th,	10.6	0–1%	East and West	clay loam 25.4% sand 38.5% silt 36.1% clay	52.5°F	52.2°F
Canyon along east and west bound lanes of FM 1714, 0.25 mile west of US Highway 87 S	2	0–1%	North and South	sandy loam 55% sand 27.5% silt 19.9% clay	54.9°F	59.5°F
Lelia Lake off east and west bound lanes of FM 1755, 0.124 mile west Lelia Lake on US Highway 87 N, 1 mile north on FM 1755	3.46	0–1%	North and South	loamy sand 85.1% sand 9.9% silt 5% clay	56.8°F	60.4°F

Experiment Site Average Temperature and Precipitation

Across all four sites the early (February 2009 through April 2009) temperatures (ambient and at 3.15-inch soil depth) were warmer in comparison to the following year. Early season ambient and 3.15-inch soil depth temperatures were optimal for vegetation establishment; however, the lack of moisture prevented germination of seed.

Experiment Site Design and Planting

The research team used a split-plot design for this study. The independent variables included compost and seed treatments. The dependent variable is percent cover. There were four replications at each site, and eight plots per replication which results in 32 experimental units per site. Plot designs are shown by locations in Figures 11–14 and Tables 11–14. The control used was the native seed bed plus soil treatment (ROW + Soil [no compost, bare soil]). Glyphosate (0.3 gal/acre) was applied on September 19, 2008, prior to plot preparation at each site. This herbicide was applied to prevent existing vegetation from interfering with the re-vegetation effort.

The sites used compost manufactured topsoil (CMT), blended-on-site (BOS), consisting of 75 percent topsoil and 25 percent compost (from a local cattle manure composting facility). The CMT was applied to half the treatment plots (equivalent to about 1 inch depth on the soil surface) at each site using a Mohrlang manure spreader on a Mack CH600 truck. The compost had a mean of 23.53 percent organic matter across all four sites. An 8-ft King Cutter skeleton disk was used to disk all treatments to a depth of 4 inches. A Great Plains 3P605 no-till drill was used to plant the seeds and apply 100 lb N/acre fertilizer. A 20-10-10 fertilizer blend was applied at a rate of 500 lb/acre. Four seeding mixtures, chosen by soil type and district, (TxDOT recommended seed mixtures) were used:

- Cool season temporary and permanent planted in fall 2008 (C&W).
- Cool season temporary planted in fall 2008 and terminated in spring 2009 then permanent planted into residue (C-T, W).
- Permanent only planted in spring 2009 (W).
- Native seed bed (ROW, right of way).

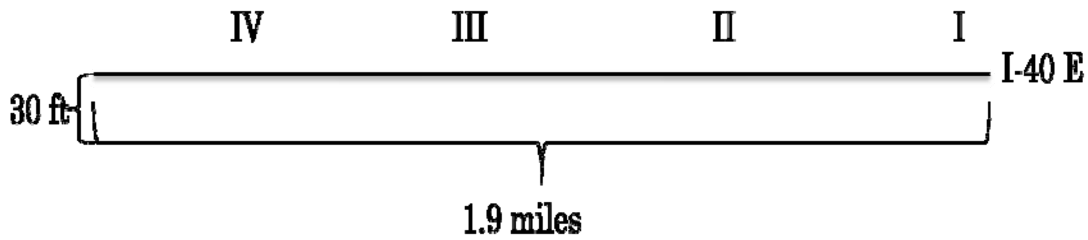


Figure 11. Adrian Site Plot Locations.

Table 11. Adrian Site Plot Design.

Adrian Site							
Rep. 1							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
ROW	W	C&W	C-T, W	W	ROW	C&W	C-T,W
Rep. 2							
BOS	BOS	BOS	BOS	Soil	Soil	Soil	Soil
C-T, W	ROW	C&W	W	C-T, W	C&W	ROW	W
Rep. 3							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
C&W	C-T, W	W	ROW	ROW	W	C&W	C-T, W
Rep. 4							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
ROW	C-T, W	C&W	W	W	ROW	C&W	C-T, W

Compost was applied at the Adrian site on October 1, 2008, and was disked on November 10, 2008. This site was planted with C-T, W and C&W seed mixtures, and fertilized on November 11, 2008. The W seed mixture was planted and fertilized on February 20, 2009. The C-T, W permanent grass mixture was planted on May 8, 2009.

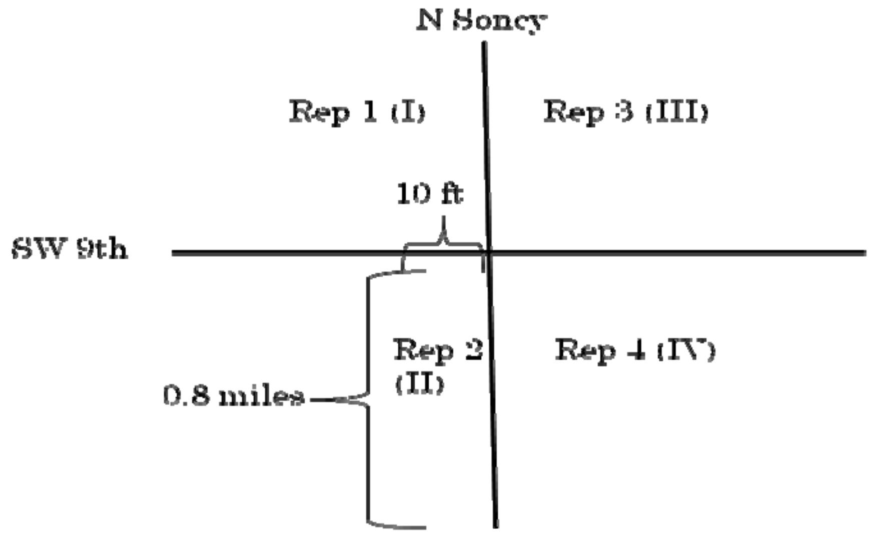


Figure 12. Amarillo Site Plot Locations.

Table 12. Amarillo Site Plot Design.

Amarillo Site							
Rep. 1							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
W	C-T, W	C&W	ROW	C&W	C-T, W	ROW	W
Rep. 2							
BOS	BOS	BOS	BOS	Soil	Soil	Soil	Soil
W	C&W	ROW	C-T, W	C&W	C-T, W	W	ROW
Rep. 3							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
C&W	C-T, W	W	ROW	C&W	W	ROW	C-T, W

Researcher applied compost at the Amarillo site on October 9, 2008, and disked the soil on November 6, 2008. This site was planted with C-T, W and C&W seed mixtures and fertilized on November 7, 2008. The W seed mixture was planted and fertilized on February 20, 2009. Researchers planted the C-T, W permanent grass mixture on May 8, 2009.

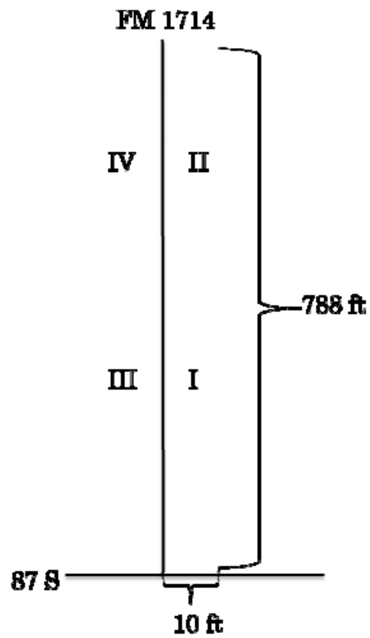


Figure 13. Canyon Site Plot Locations.

Table 13. Canyon Site Plot Design.

Canyon Site Rep. 1							
BOS	BOS	BOS	BOS	Soil	Soil	Soil	Soil
C&W	W	ROW	C-T, W	W	C-T, W	ROW	C&W
Rep. 2							
BOS	BOS	BOS	BOS	Soil	Soil	Soil	Soil
C&W	W	ROW	C-T, W	C-T, W	C&W	ROW	W
Rep. 3							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
C-T, W	C&W	ROW	W	ROW	W	C-T,W	C&W
Rep. 4							
BOS	BOS	BOS	BOS	Soil	Soil	Soil	Soil
C&W	ROW	W	C-T, W	C-T, W	W	C&W	ROW

Compost was applied at the Canyon site on November 10, 2008, and was disked on November 20, 2008. This site was planted with C-T, W and C&W seed mixtures and fertilized on November 21, 2008. The W seed mixture was planted and fertilized on February 20, 2009. The C-T, W permanent grass mixture was planted on May 8, 2009.

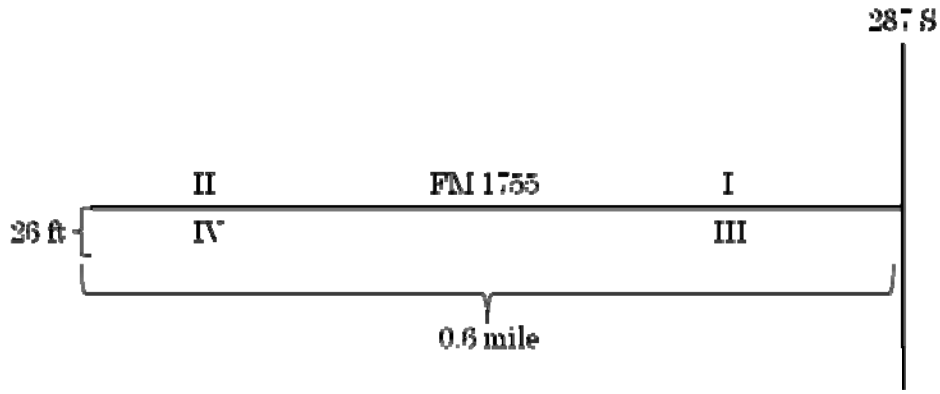


Figure 14. Lelia Lake Site Plot Locations.

Table 14. Lelia Lake Site Plot Design.

Lelia Lake Site							
Rep. 1							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
ROW	W	C&W	C-T, W	W	ROW	C&W	C-T, W
Rep. 2							
BOS	BOS	BOS	BOS	Soil	Soil	Soil	Soil
C-T, W	ROW	C&W	W	C-T, W	C&W	ROW	W
Rep. 3							
Soil	Soil	Soil	Soil	BOS	BOS	BOS	BOS
C&W	C-T, W	W	ROW	ROW	W	C&W	C-T, W

Compost was applied at the Lelia Lake site on November 11, 2008, and was disked on November 20, 2008. This site was planted with C-T, W and C&W seed mixtures and fertilized on November 21, 2008. The W seed mixture was planted on February 20, 2009. The C-T, W permanent grass mixture was planted on May 8, 2009.

Data Collection

Percent of vegetation covers were determined using the line transect method as described by Tansley and Chipp (*55*). Vegetation cover was collected at all sites in May, June, and August 2009, and June 2010. Two line transects were assayed in every experimental unit at each sampling. The readings were taken every 15.75 inches. The research team determined percent cover by dividing the number of plants counted by the total number of readings and multiplying by 100 to get a percentage. The researchers identified and then grouped the observed plants into several categories: cool season annuals, cool season perennials, warm season annuals, warm season perennials, and planted.

A HOBO data logger (Onset Corporation) weather station, present at each site, measured:

- Soil temperature at 3.15-inch depth.
- Minimum and maximum daily ambient temperature.
- Daily precipitation from February 2009 through May 2010.

At the Amarillo site, due to rodent damage, soil temperature was limited to February 2009, and ambient temperature was limited to February 2009 through September 2009.

Statistical Analysis

Researchers used a multivariate analysis of variance test to analyze percent covers of vegetation by date, compost, seed mixture, compost and seed mixture. They took repeated measures into account using PROC GLM in SAS (*56*) version 9.1 and the type I SS.

A SAS analysis of categorical data used the Fisher exact option to determine if compost influenced the kind of vegetation present by evaluating if compost gave way to more weed species than the native grasses that were planted.

The researchers used a multivariate analysis of variance test to analyze percent covers of vegetation by looking at each sample date individually, and vegetative class (planted, annuals, and perennials). Means were separated using a protected LSD. A PROC GLM in SAS (*56*) version 9.1 and the type I SS was used.

RESULTS AND DISCUSSION

At the Adrian site, researchers observed differences in percent cover beginning with the June 2009 sample data, when the percentage of cover in compost treatments resulted in 10.8 percent more cover. The compost advantage in the last two sampling date was about 58 percent. The treatments without compost did not achieve more than 22 percent vegetative cover. While the compost treatment plots achieved the required 70 percent percentage cover per CGP within 9 months after planting, and the no-compost treatment plots could not reach that required minimum coverage even after 20 months. The Adrian site received favorable precipitation from mid-June 2009 through mid-July 2009, which explains the jump in percent cover from June 2009 to August 2009. The increase in percent cover is more likely attributed to an increase in plant biomass/ area covered rather than an increase in the number of new plants. Annuals dominated the vegetative composition, with density levels less than 20 percent peaking at ~50 percent cover by June 2010. Annuals were the only plant species in the no-compost treatment, while the compost treatment maintained the planted perennials and annuals (see Figure 15). There was a time by compost interaction which may have been caused by a combination of precipitation and temperature.

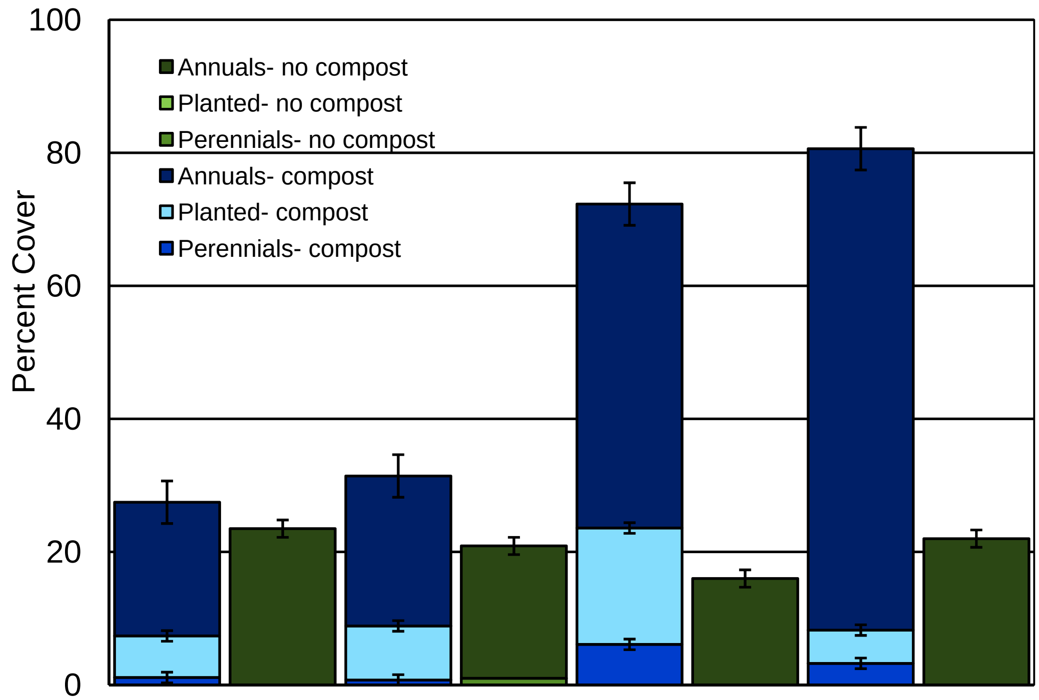
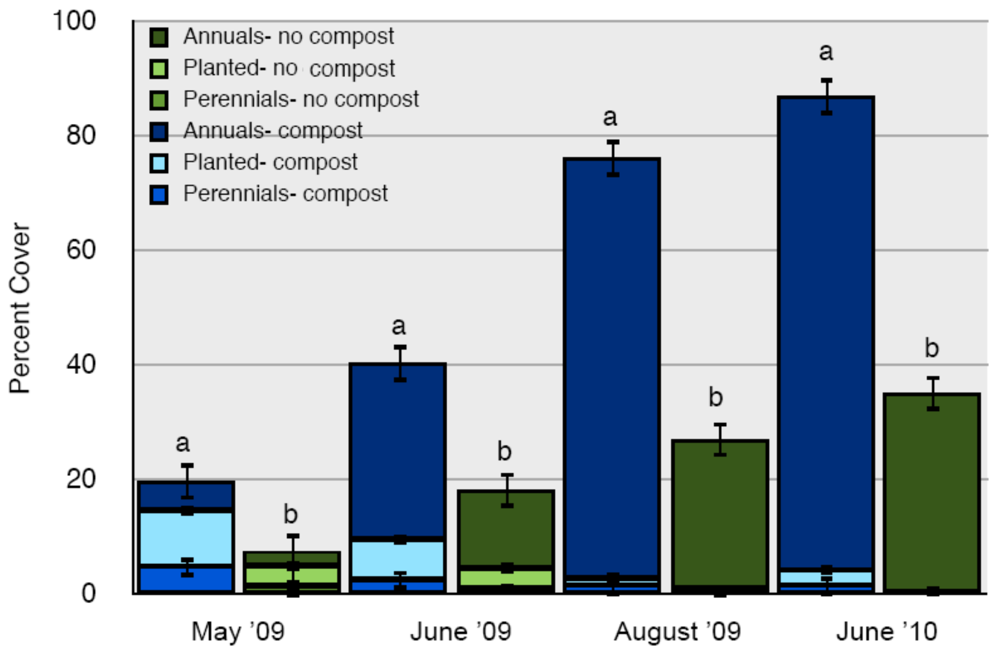


Figure 15. Adrian Site.

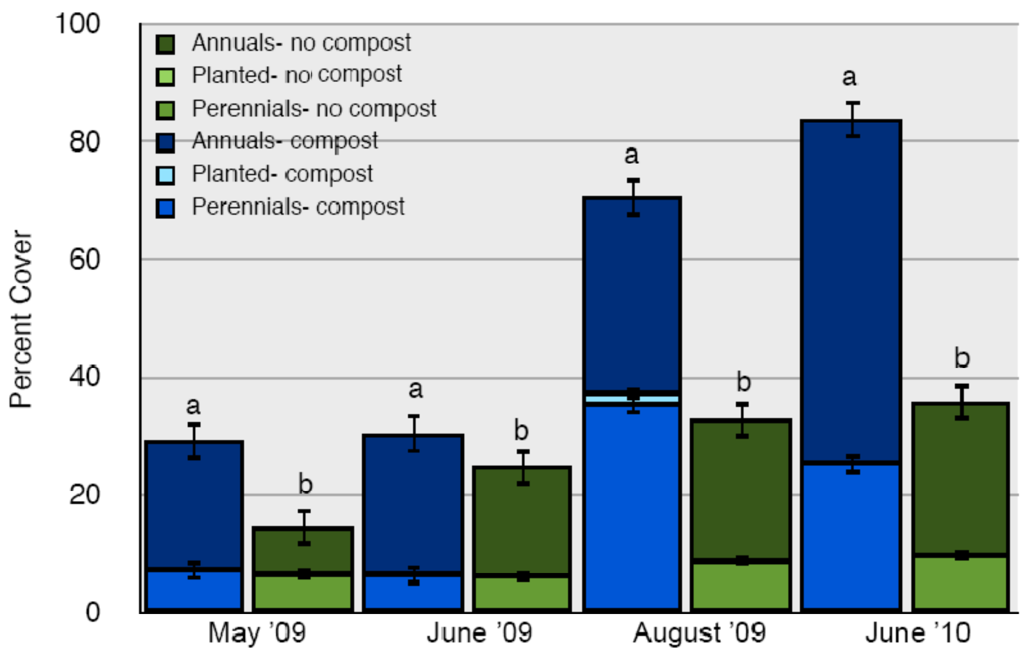
Observations at the Amarillo included differences in vegetative cover beginning with the first reading date, May 2009, when the cover in compost treatments resulted in 21.6 percent more cover (Figure 16). The compost advantage in the last two sampling dates was about 48 percent. The treatments without compost did not achieve more than 35.1 percent vegetative cover. While the compost treatment plots achieved the CGP minimum required percentage cover within 9 months after planting, the no-compost treatment plots could not reach that required minimum coverage even after 20 months. The Amarillo site received favorable precipitation from June 2009 through August 2009 (see Figure 11) which explains the jump in percent cover from June 2009 to August 2009. There was a time-by-compost interaction which may have been caused by a combination of precipitation and temperature. There was a compost-by-seed mixture interaction which may be explained because more of the warm season annuals were in the vegetative make-up during the June 2009, August 2009, and June 2010 sampling dates. Warm season annuals dominated the vegetative composition. They started with less than 2 percent cover and peaked at ~55 percent cover by June 2010.



*Means followed by same letter are not significantly different (P<0.05)

Figure 16. Amarillo Compost vs. No-Compost Means, May 2009–June 2010.

At Canyon, researchers observed differences in vegetative cover beginning with the first reading date, May 2009, when the cover in compost treatments resulted in 4.6 percent more cover (Figure 17). The compost advantage in the last sampling date was about 48 percent. The treatments without compost did not achieve more than 36.3 percent cover. While the compost treatment plots achieved the percentage cover within nine months after planting, the no-compost treatment plots could not reach that required minimum coverage even after 20 months. The Canyon site received favorable precipitation from May 2009 through July 2009 (Figure 11), which explains the similarities in the cover readings in May 2009 and June 2009. Since The City of Canyon and WTAMU Feedlot received heavy precipitation in early August 2009 (2.4–2.6 inches) it can be assumed that the Canyon site received comparable precipitation which can explain the jump in the August 2009 reading date. This site was in a residential area where homeowners had planted bermudagrass, which was mowed frequently allowing the spread of bermudagrass giving the grass a chance to establish. Bermudagrass is a perennial, which explains why the coverage for perennials is so high. This can explain why the no-compost treatment had the highest percent cover out of all locations at the Canyon site. There was a time-by-compost interaction that may have been caused by a combination of precipitation and temperature.



*Means followed by same letter are not significantly different (P<0.05)

Figure 17. Canyon Site Compost vs. No Compost Means, May 2009–June 2010.

At Lelia Lake, researchers observed differences in vegetative cover beginning with the June 2009 reading date, when the cover in compost treatments resulted in 4.8 percent more cover (Figure 18). The compost advantage in the last two sampling dates was about 63 percent. The treatments without compost did not achieve more than 28.8 percent cover. While the compost treatment plots achieved the percentage cover within 9 months after planting, and the no compost treatment plots could not reach that required minimum coverage even after 20 months. The Lelia Lake site received favorable precipitation throughout the 2009 growing season (Figure 11) which explains the differences between the compost and no-compost treatments in August 2009 and

June 2010 readings. The Lelia Lake site had similar results as the Adrian location with what was planted only growing in treatments that received compost. Annuals dominated the vegetation across all four sites, but in treatments receiving compost there was a greater diversity of plant species, as opposed to only annuals in the no-compost treatment. There was a time-by-compost interaction that may have been caused by a combination of precipitation and temperature.

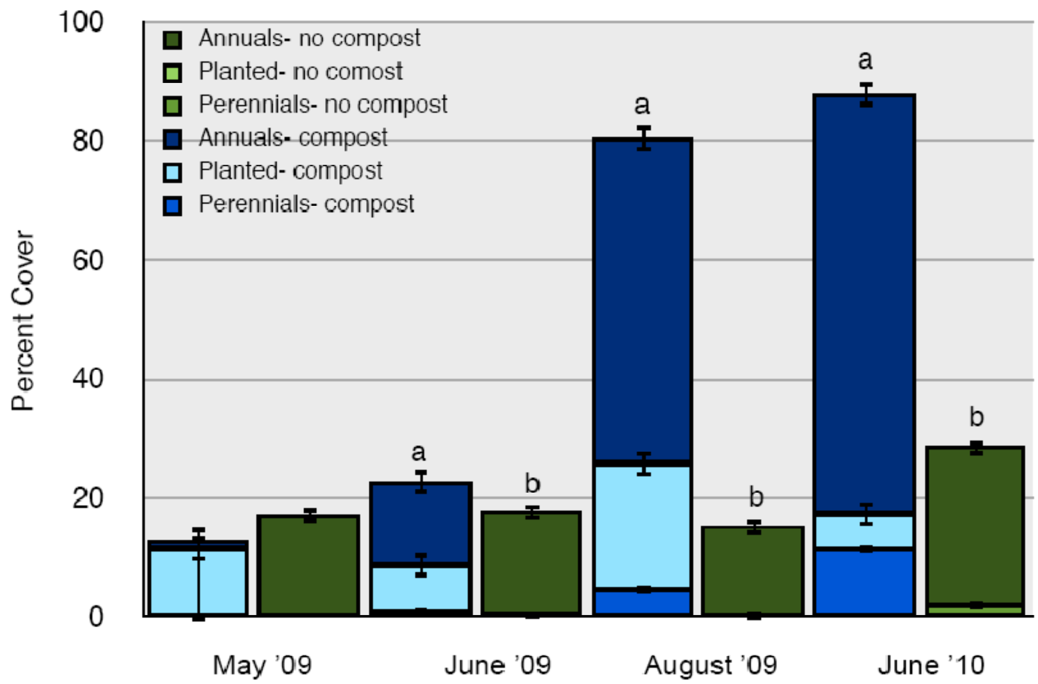


Figure 18. Lelia Lake Site Compost vs. No Compost Means, May 2009–June 2010.

The percent cover data for all treatments across all four sites were combined, and grouped by class (Figure 19) using June 2010 data. None of the un-composted treatments had achieved 70 percent absolute vegetative cover within 20 months, while 96.8 percent of the composted treatments met the 70 percent cover requirement to file a NOT with TCEQ.

A Chi Square analysis, with the Fisher exact option, was performed in SAS to determine if compost affected the vegetative cover present (*62*). The results showed cover was independent upon compost treatments ($P<0.001$) across all locations.

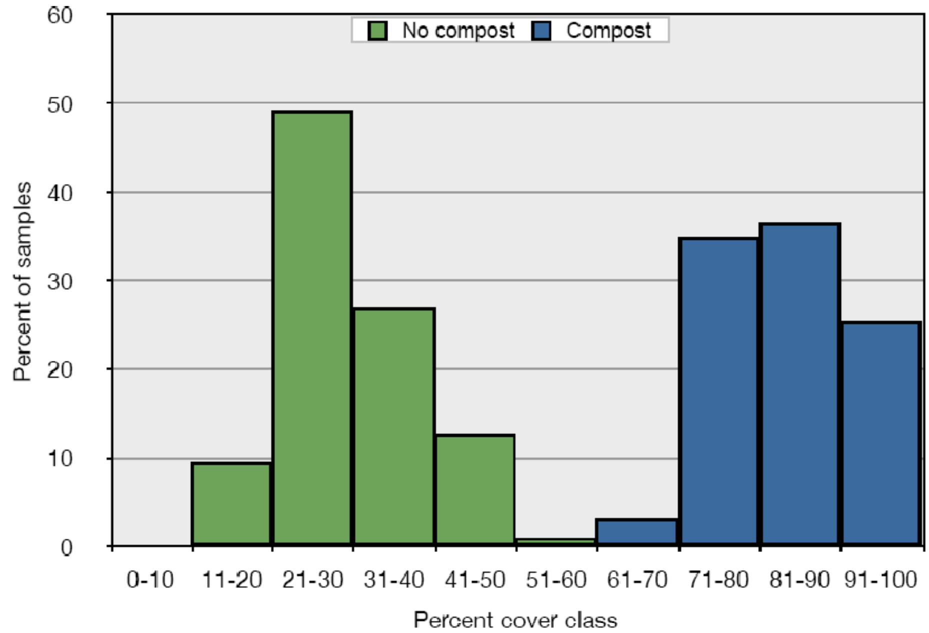


Figure 19. Percent of Samples by Class for All Treatments and Locations Combined for Compost vs. No-Compost, June 2010.

Seed Mixtures

There were no overall vegetative cover differences attributable to seed mixtures at the four sites. Seed mixtures were not statistically significant at any of the four sites (Figures 20–23). Annuals dominated the vegetative composition across all sites. The Canyon site had more perennials than the other three sites because of the residential area spreading bermudagrass. The Lelia Lake site had the most planted species present because the compost was able to hold the seeds in place, unlike the no-compost treatment where the seed mixtures planted were subject to wind erosion. There was a time-by-seed mixture interaction at Adrian, Amarillo, and Canyon, which may have been caused by a combination of precipitation and temperature and not all seed mixtures were performing the same way. The Amarillo site had a compost by seed mixture by time interaction which may have been influenced by favorable environmental conditions. Amarillo received significant precipitation events and temperatures that favored vegetative growth during later sampling dates.

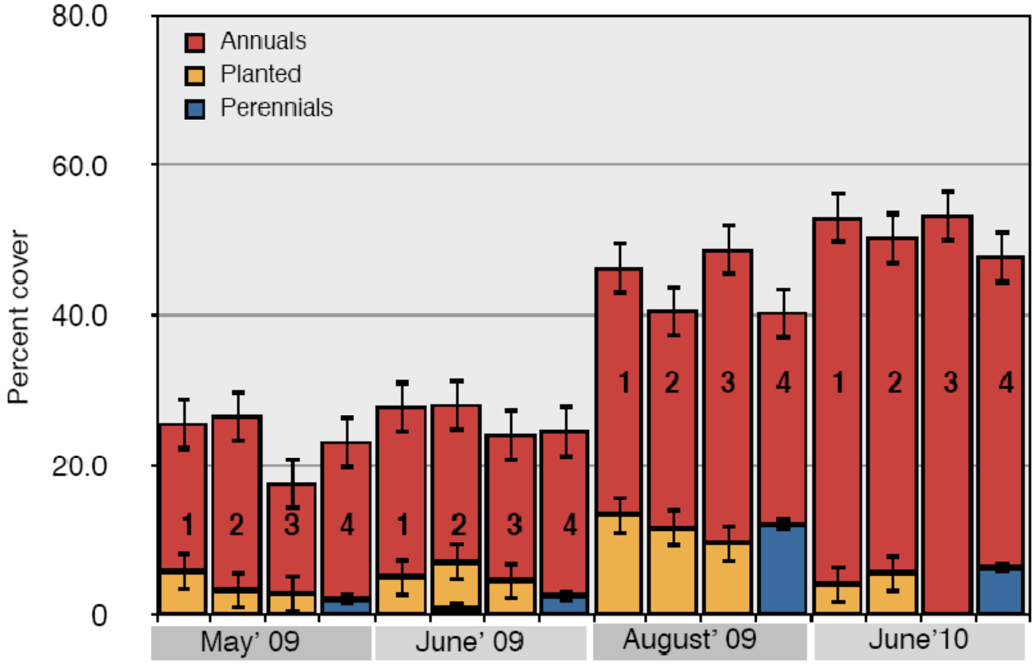


Figure 20. Adrian Site Seed Mixtures Means, May 2009–June 2010.

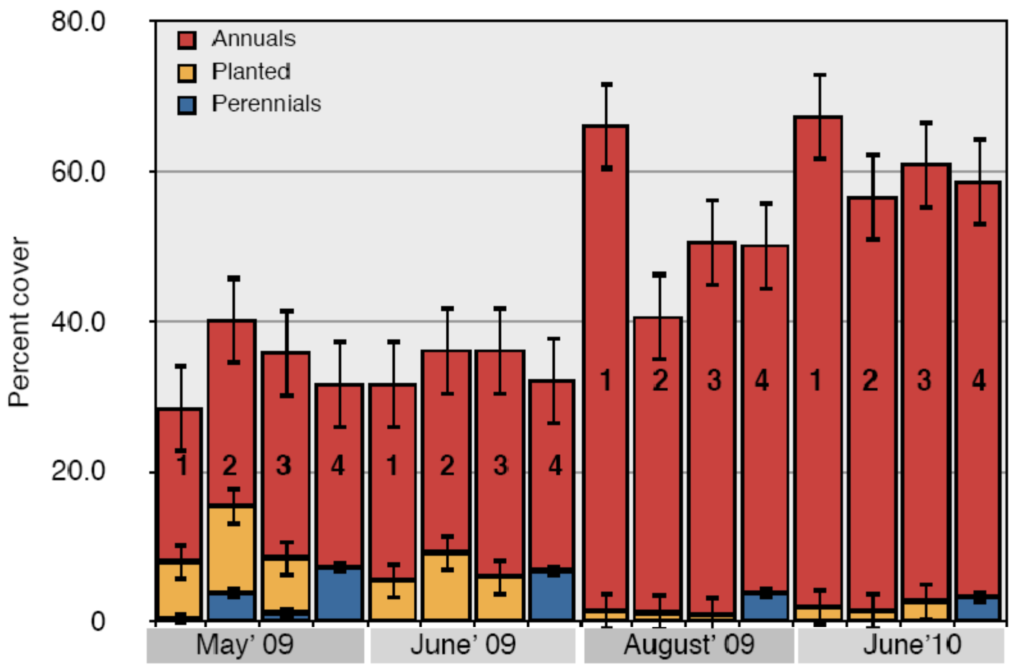


Figure 21. Amarillo Site Seed Mixtures Means, May 2009–June 2010.

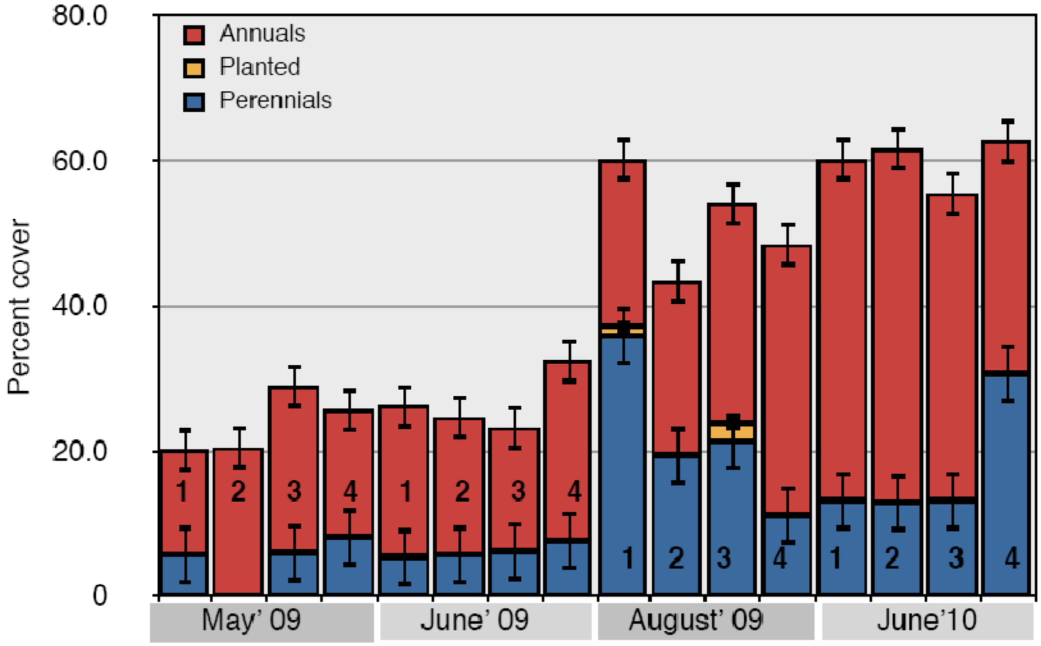


Figure 22. Canyon Site Seed Mixtures Means May 2009–June 2010.

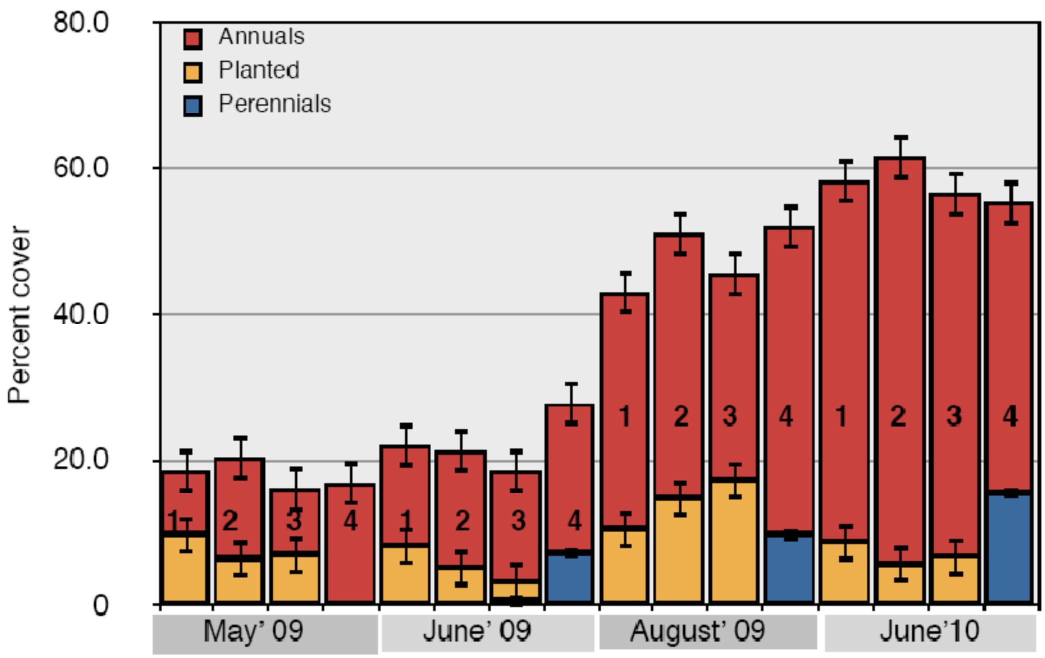


Figure 23. Lelia Lake Seed Mixtures Means, May 2009–June 2010.

Other Observations

On May 22, 2009, researchers observed that at the Adrian site kochia was growing in the drill-seeder tracks which created micro-furrows for water to accumulate (Figure 24). The no-till drill that was used to plant the wheat created the micro-furrows. There was minimal precipitation during May 2009 at the Adrian site, but just enough for the seed to germinate. The furrow collected enough water to allow germination to occur. A difference in cover is present when looking at the upper slope (next to the road, right side of photo) compared to the drainage ditch (left side of photo). The vegetation growing in the ditch is a much higher percent cover than the slope by the road because the ditch is receiving run-off precipitation from both east and west bound lanes of I-40. The grade of the slope allows for quick runoff of precipitation to the drainage ditch in the middle allowing greater percolation and infiltration into the soil surface and profile.

Figure 24. Adrian Site Kochia in Micro-Furrows 14 Days after Planting.

Semi-arid environments challenge re-vegetation efforts. Lack of regular precipitation is common in the Texas Panhandle, and compost can help retain the moisture making it available to vegetation. Precipitation will most likely runoff or evaporate on soil without compost. Planting times did not create an advantage to any of the treatments. By using compost and the native seed stores present in salvaged topsoil, the vegetative cover requirements for meeting the NOT can be accomplished within seven to eight months after planting regardless of the time of the year the planting occurs.

CONCLUSIONS FROM EXPERIMENTAL SITES

In this study, compost provides a higher percent cover after seven to eight months when compared with bare soil. Compost increased the percent cover to over 80 percent across all four sites by the June 2010 reading. The treatments without compost peaked at 36 percent in the June 2010 reading. The most likely reason for this increased vegetation cover may have some from compost's ability to limit evaporation, increase the water holding capacity, improve the soil structure, and add nutrients and organic matter. Previous TxDOT demonstration projects using compost on the roadside have shown similar results. Annuals dominated the vegetation across all four sites, but in treatments that received compost there was a greater diversity of plant species, as opposed to only annuals in the no-compost treatment.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

SUMMARY AND CONCLUSIONS

Vegetation establishment play a vital part in TxDOT's ability to meet the regulations of the Texas Pollutant Discharge Elimination System. Although growing grass on the roadside seems to be a simple task to the uninformed, this process, from design to installation, requires many items to be executed in a consistent manner specific to the needs of the project and district. Vegetation establishment/management is often the last part of the project and therefore receives little attention. This may be due in part to:

- A lack of understanding as to how to evaluate and conduct performance based requirements for this aspect of the project.
- Vegetation's priority in the project's budgetary allocation.

The project inspection process needs improvement. According to the TxDOT personnel interviewed during the course of this project, an estimated 80 percent of vegetation establishment projects are not implemented according to conventional guidelines and standards. Inspector training is critical and lacking. Inspectors are responsible for the entire project (not just vegetation establishment) and therefore their knowledge base must be broad. The Vegetation Management Section in Austin will conduct training when invited, but this is infrequent due to conflicting priorities and limited personnel.

RECOMMENDATIONS FOR THE VEGETATION ESTABLISHMENT PROCESS

The research team identified several areas that could be addressed to improve vegetation establishment. These recommendations are grouped in two categories, procedural and technical issues, and are based on data obtained from the literature and discussion with TxDOT staff.

Procedural Issues

Procedural issues are those dealing more with planning and management. Many of the problems cited in establishing vegetation are rooted in conditions that prevent the right information being available and applied at the right time or due to human errors, omissions in judgment, or application. These types of problems are related to project execution rather than any technical deficiencies.

Ecologically Regionalized Approach

The problems with vegetation establishment faced by the districts are highly varied and due in part to the diversity of regional climates, soils, and plant communities. Vegetation science is a dynamic field that must be adapted to a changing and often complex set of circumstances. To adequately meet these challenges, each district must be able to structure their resources and responses to its particular needs. The current guideline system is very general and requires too much judgment on the part of people not well-qualified to make those decisions.

Initially, discussion with TxDOT included an ecologically regionalized approach to see if modifications should be made in the current district specified rates to adapt the existing standards for vegetation establishment to the ecological characteristics of each district. These standards would be based on the eco-regions of the state overlain on the existing district boundaries. Methodologies, materials, techniques, timetables etc, would be individualized to each region/district. However, TxDOT decided to proceed with the project within the parameters of the current TxDOT specifications.

Current Training Practices

Most TxDOT inspectors are not adequately trained and few, if any, have formal education in any field of vegetation or soil science. This lack of adequate relevant experience or training often leads to poor execution of the vegetation installation procedures resulting in delays in establishment and exposing the project to erosion problems and possible regulatory violations.

Some contractors are very knowledgeable, but typically expertise is very low. In discussions with TxDOT staff, researchers found out that DBE contractors are the most problematic. It is common for contractors to take on so much work that they cannot respond when needed. Many are located long distances from project sites and are reluctant to visit sites regularly. BMPs are not being repaired when required.

Initiating a program of intensive training and certification for inspectors and contractors for the relevant field will help close the gap in training.

Pay Items

Prime contractors do not take vegetation establishment seriously enough. They rarely devote the attention and resources necessary to establish vegetation within the required time. Items such as fertilizer (Item 166) are often subsidiary to other bid items and therefore are difficult to track for compliance to the specification. The research team recommends making some parts of the vegetation establishment process as a separate pay item to ensure proper application. This could be adapted to meet each districts problems/needs. The standard sheet example found in VEGDAT demonstrates how this can be accomplished and adapted to district specific requirements.

The Preconstruction Conference

The importance of vegetation establishment has been historically under-emphasized. It is a vital component of regulatory requirements and the underlying basis of many violations. Contractors often focus on project items that pay more per item than those required to meet the SW3P requirements.

According to TxDOT personnel across the state, there seems to be a breakdown in communication that extends from the designer to contractor to the inspector. The preconstruction meeting is an opportune time to:

- Make everyone aware of vegetation’s role in regulatory compliance.
- Emphasize the importance of salvaging topsoil.
- Make the contractor more aware of the importance of the SW3P as part of the project.

SW3P Compliance

TxDOT is the permitee on CGP Notice of Intent submitted to TCEQ and is therefore held accountable for any regulatory infractions. The next recommendation is to require the prime contractor to become co-permittee. As a co-permittee, the regulatory compliance issues, and therefore potential for violations, becomes the responsibility of the contractor as well. This is common practice in surrounding states.

District Level Vegetation Expertise

Support for inspectors is severely lacking in certain districts. In some cases, the only available resource is the Maintenance Division by phone. On-site expert support is sometimes not available within the district. Ineffective decisions in the field have led to delays in vegetation establishment, repeat installations, and delays in getting the NOT submitted in a timely manner.

The research team recommends designating a district-level support person for all erosion control BMPs and vegetation installation projects items. The position should require an educational background in soils and vegetation. To attract qualified candidates, the position should be comparable in pay to similar, degreed positions in the department. Examples of such candidates are landscape architect, vegetation manager, environmental coordinator, or other environmental science degrees with a vegetation background. The position might be housed in the construction section.

Technical Issues

Technical issues are items that deal directly with the type or method of installation. These recommendations will apply only to those districts where they are suited. A thorough study of each district's needs, climate, resources, and other factors affecting re-vegetation will determine applicability of these recommendations. The result will be a detailed district standard, created with division and district personnel and tailored to their specific needs and conditions.

Temporary Seeding

Temporary seeding is often used when permanent seeding is out-of-season. Some districts are planting into temporary cool season stands after mowing and reporting good success. Over-seeding into existing cover crops is a tool often used in agriculture and could be a tool for districts. Generally, this is done when seed needs to be available when rainfall occurs which may not coincide with typical seeding protocols.

Some districts currently practice seeding permanent grasses with temporary seeding in fall with reported good results. However, there are no standards or guidelines for this practice and the degree of success or failure is not documented. Dormant seeding (seed sown during vegetation's dormant season so available when rainfall arrives) should be adopted as an available tool for those districts whose climate and conditions favors this practice. The experimental sites data and anecdotal data from the different district personnel support this practice.

Develop guidelines and standards regarding:

- How to use temporary cover crops as a tool for rapid stabilization and long-term permanent seed establishment.
- Providing better information on the applicability, use, and techniques of dormant seeding permanent vegetation with temporary seeding.

Seed Mixes

Native species dominate the current seed mix, some of which are slow to germinate and establish. In certain regions, this situation is an advantage, but in others, slow establishment often leads to erosion problems. Rapid establishment of sod-forming species will reduce erosion risk.

The research team recommends looking at the current seed mixes and considering re-orienting the seed mixes to focus on rapid establishment of sod-forming grass species, particularly in erosion-prone areas.

Seeding Rates

The seeding rates and mixes currently used in the TxDOT specification will probably continue to prompt discussion between the districts and division offices. The experimental plots in west Texas demonstrated that vegetation could be established more quickly and meet the required 70 percent cover using compost manufactured topsoil in planting bed preparation. The results of these plots confirm previous TxDOT experiences regarding the use of compost on the roadside.

TxDOT's seeding rates per species are designed to address the variations of soil and micro-climate on a site. The current rates may be too low for a rapid establishment if a significant portion of the seed is not suited to the conditions found on the site. Seed suitability can lead to sparse stands of grass and/or allow weeds to out-compete seeded grasses. In either case, erosion potential is increased.

Consider an adjustment to the seed rates to compensate for higher mortality rates of seeded species due to poor conditions and/or competition from weed species. Develop a zone-system of seeding that concentrates sod-forming seed in the safety clear-zone (the roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles) (*57*). Use a mix with higher numbers of native species in areas outside the clear-zone or where space allows.

Salvaged Topsoil

The greatest key to successful vegetation establishment is probably topsoil recovery, storage and reapplication. This cannot be overstated. These three activities conserve the nutrients, organic matter, microbial population, seed bank, and moisture—all critical parameters for vegetation establishment. For highly urbanized areas with right-of-way constraints, salvaging and stockpiling topsoil may not reasonable. In these instances, designers may consider using soil amendments, compost, etc. to rehabilitate the soil. Performance data from the west Texas experimental plots produced very good vegetative cover, over 80 percent within 8 months of planting, using compost manufactured topsoil. Develop efforts to promote topsoil salvaging for each project as emphasized during the preconstruction conference.

RECOMMENDATIONS FOR IMPLEMENTATION

Training

Based on the results of this project, there are gaps in training for the vegetation establishment process that need to be filled, from the designer to the contractor to the inspectors. Designers may not have the necessary knowledge in soils and plants to make design decisions regarding vegetation. There are many TxDOT research reports, existing manuals and guidance documents, and specifications regarding the vegetation process available to the designer and other personnel. However, the majority of this information is found as bits and pieces in numerous documents and searching for these can be quite overwhelming.

As discussed in previous sections of this report, not all contractors are alike in knowledge base and performance. Many other DOTs are implementing training and certification programs for their staff, consultants, and contractors. These efforts will help ensure a better measurement of performance and accountability.

Training for TxDOT district personnel, construction managers and contractors could be combined into a program and be required for contractors after the job is let/won or as a pre-qualification. This training should include an emphasis on vegetation establishment, how it is accomplished, its role in regulatory compliance, and the TxDOT/contractor responsibilities.

The Vegetation Establishment Guidance for Decisions Assistance Tool was developed to further educate the designer not familiar with the vegetation establishment process and incorporate the existing available information in a readily assessable manner. The Roadside Vegetation Establishment Quick Reference Field Guide was designed to meet the needs of field personnel. The researchers recommend a training program using the VEGDAT for Engineers-in-Training and other TxDOT personnel tasked with decision-making regarding vegetation. This training may consist of a formal program or be structured as a workshop.

REFERENCES

1. Texas Commission on Environmental Quality. *TPDES General Permit No. TXR 150000*. http://www.tceq.state.tx.us/assets/public/permitting/waterquality/attachments/stormwater/txr150000.pdf. Accessed March 2010.

2. Texas Department of Transportation. *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. Austin, Texas. 2004. http://www.dot.state.tx.us/business/specifications.htm. Accessed August 2008.

3. Texas Department of Transportation. *Storm Water Management Guidelines for Construction Activities.* 2002. http://www.txdot.gov/txdot_library/consultants_contractors/publications/environmental_resources.htm#storm. Accessed November 2006.

4. McFalls, J.A., W. Rogers, C. Robinson, B.J. Storey, B. Stewart, M. Li, J.R. Schutt, V. Saxena. *Water Retention Techniques for Vegetation Establishment in TxDOT West Texas Districts.* Report 0-5748-1. Texas Transportation Institute, College Station, Texas. 2010.

5. Texas Department of Transportation. *A Guide to Roadside Vegetation Establishment, 1st Edition.* Vegetation Management Section, Maintenance Division. January 2004.

6. Texas Department of Transportation. *Storm Water Field Inspector's Guide*. Environmental Affairs Division. June 2004.

7. Bowmer, W. J., and W. G. McCully. *Establishment of Bermudagrass Seeded with Annual Ryegrass.* Research Report 67-7. Texas Transportation Institute, College Station, Texas. 1968.

8. McCully, W.G., Bowmer, W.J., and J.L. Stubbendieck. *Problems in Establishing or Maintaining Vegetation on Roadsides*. Research Report 142-1. Texas Transportation Institute, College Station, Texas. 1970.

9. McCully, W.G., and J. L. Stubbendieck. *Establishment and Management of Roadside Vegetation*. Research Report 142-3. Texas Transportation Institute, College Station, Texas. 1972.

10. Allen, T.J., W.G. McCully. *Establishment and Management of Roadside Vegetation*. Research Report 182-2F. Texas Transportation Institute, College Station, Texas. 1976.

11. Davies, F. T. and W.G. McCully. *Potential for Using Mycorrhizal Plants to Revegetate Texas Highway Rights-of-Ways*. Research Report 902A-1. Texas Transportation Institute, College Station, Texas. 1984.

12. Davies, F.T. and W.G. McCully. *Enhancement of Texas Highways Vegetation with Mycorrhizal Fungi.* Research Report 902-3. Texas Transportation Institute, College Station, Texas. 1986.

13. McCully, W G; E.E. McWilliams, M.J. Kaspar, and S. Grigg. *Propagation of Wildflowers for Roadside Use*. Research Report 902-4. Texas Transportation Institute, College Station, Texas. 1986.

14. McCully, W.G., E.E. McWilliams, and F.T. Davies. *Propagation of Some Native Woody Landscaping Plants.* Research Report 902-5. Texas Transportation Institute, College Station, Texas. 1896.

15. Schutt, J.R., and M. Teal. *Prairie Restoration: an Evaluation of Techniques for Management of Native Grass Communities in Highway Roadsides of Texas.* Research Report 944-1. Texas Transportation Institute, College Station, Texas. 1994.

16. Simpkins, C.L. *Establishment of Grass Mixtures on Roadsides*. Research Report 902-6. Texas Transportation Institute. 1994.

17. Fedler, C., P. Pearson, J. Borrelli, C. Green, M. Galyean, T. Provin and D. Rivera. *Utilizing Compost as an Alternative Method to Standard Seedings: Final Report.* Research Report 0-4571-1. Center for Multidisciplinary Research in Transportation. 2003.

18. McFalls, J.Z. M. Li, J. Schutt, D. Foster, and J. Lee. *Comparison of the Use of TxDOT Seeding Mixes and Fertilizer Rates to the Use of Native Grass*. Research Report 0-5212-1. Texas Transportation Institute, College Station, Texas. 2007.

19. Li, M., L. Wheelock and J. Schutt. *Successional Establishment, Mowing Response, and Erosion Control Characteristics of Roadside Vegetation.* Research Report 0-4949. Texas Transportation Institute, College Station, Texas. 2007.

20. Kira, T., H. Ogawa, and N. Sakazaki. "Intraspecific competition among higher plants. I. Competition-density-yield inter-relationships in regularly dispersed populations. .:" *Journal of Institute Polytechnical,* Osaka City University 4: 1-16. 1953.

21. Miller, C. F. and J. A. Dickerson. *The Use of Native Warm Season Grasses for Critical Area Stabilization.* 1999. http://plant-materials.nrcs.usda.gov/pubs/NJPMSSY405.pdf. Accessed 2007.

22. Minnesota Department of Natural Resources. *Using Native Prairie Species for. Reclaiming Aggregate. Mining Sites, Fact Sheet 4.* January 2001. http://files.dnr.state.mn.us/lands_minerals/aggregate4_mar01.pdf. Accessed 2007.

23. Holzworth, L. and L. Wiesner. *Seedbed Preparation and Seeding Technical Note No. MT-58.* U. S. Department of Agriculture, Natural Resources Conservation Service. 2007.

24. Yolo County Resource Conservation District. *Strategies for Establishing California Native Grasses by Direct Seeding in the Sacramento Valley and Adjacent Foothills*. http://yolorcd.org/. Accessed 2007.

25. Decker, A. M. and T. H. Taylor, Eds. *Establishment of New Seedings and Renovation of Old Sods*, "Forages: The science of grassland agriculture." Iowa State University Press. Ames Iowa. 1985.

26. Vallentine, J. F. *Range Developments and Improvements*. New York, Academic Press. 1989.

27. Steinbacher, J. "Revegetating with native plants at drastically disturbed sites." *Erosion Control,* 17. 2000.

28. Cornell, S. *Guidelines for Re-vegetation of Disturbed Areas*. 2007. http://www.co.larimer.co.us/engineering/NPDES/seeding.pdf. Accessed 2007.

29. Bakker, J.D., S.D. Wilson, J.M. Christian. X. Li, L.G. Ambrose, and J. Waddington. "Contingency of grassland restoration on year, site, and competition from introduced grasses." *Ecological Applications.* 13(1), 2003.

30. Whisenant, S.G. *Repairing Damaged Wildlands: A Process-oriented, Landscape-scale Approach.* Cambridge University Press. 1995.

31. Darris, Dale C. *Considerations for Establishing Native Grasses from Seed for Restoration, Re-vegetation, and Erosion Control in Western Washington and Western Oregon. Plant Materials Tech. Note No. 36*. U.S. Department of Agriculture, Natural Resources Conservation Service, Corvallis Plant Materials Center, Portland, OR 2003. http://www.plant-materials.nrcs.usda.gov/pubs/orpmctn5165.pdf. Accessed 2007.

32. Conard, R. "Applewood Golf Course: Reintroducing the shortgrass prairie and links-style golf." *USGA Green Section Record.* 30(6): 11-12. 1992.

33. Patton, A.J., D.W. Williams, Z.J. Reicher. "Establishing seeded bermudagrass." *Golf Course Management.* December: 73-77. 2004.

34. Venuto, B.C., D.D. Redfearn, W.D. Pitman, and M.W Alison. "Impact of seeding rate on annual ryegrass performance." *Grass and Forage Science.* 59: 8-14. 2004.

35. Jacobs, J.S., M.F. Carpinelli, R.L. Sheley. *Rehabilitation of Weed-Infested Rangeland, MontGuide Fact Sheet #199811*. 2003. http://www.montana.edu/wwwpb/pubs/mt9811.html. Accessed 2007.

36. Dickson, T. *High Seeding Rates of Native Grasses Reduce Broadleaf Forb Diversity in a Kansas Conservation Reserve Program (CRP) Prairie Restoration*. ESA 2005 Annual Meeting, Montreal, Canada, Ecological Society of America. 2005.

37. Martin, A. and J. Harrington. *Re-Creating Diversity: The Ecological and Social Implications of Seeding Density in Prairie Restorations.* Twentieth Biennial North American Prairie Conference, University of Nebraska at Kearney. 2006.

38. Schutt, J. R. *Composition and Spacial Pattern of Herbaceous Roadside Vegetation along State Highway 6 in Robertson County, Texas*. Texas A&M University, College Station. 2000.

39. Tinsley, M.J., M.T. Simmons, and S. Windhager. "The establishment of native versus non-native herbaceous seed mixes on a revegetated roadside in Texas." *Ecological Engineering* 26(3): 231-240. 2006.

40. Sprow, M. "Saving native Texans." *County.* Mar/Apr**:** 25-27. 2006.

41. Hays, B.K., M. Wagner, F. Smeins, and R.N. Wilkins. *Restoring Native Grasslands*, L-5456. Texas A&M University System, Texas Cooperative Extension. 2005.

42. Leopold, Rick. Conservation Agronomist. NRCS Zone 4 Office, Bryan, Texas. Interview 2007.

43. Duble, R.L. *Specifications for Turfgrass Establishment*. Texas Cooperative Education Extension. Texas A&M University. http://plantanswers.tamu.edu/turf/publications/estab.html. Accessed March 2007.

44. Dorner, J. *An Introduction to Using Native Plants in Restoration Projects*. http://www.nps.gov/plants/restore/pubs/intronatplant/planting.htm. Accessed March 5, 2006.

45. Polster, D.C. *Natural Vegetation Succession and Sustainable Reclamation*. 1997. http://www.for.gov.bc.ca/nursery/fnabc/Proceedings/NatVegSuccsn.htm. Accessed March 2007.

46. Turner Seed. Seed Availability List. http://www.turnerseed.com/site/GrassSeed.asp. Accessed 2007.

47. Willms, W.D., B.H. Ellert, H.H. Janzen, and H. Douwes. "Evaluation of native and introduced grasses for reclamation and production." *Rangeland Ecology & Management,* 58(2): 177-183. 2005.

48. Natural Resource Conservation Service. *Conservation Practice Standard, Critical Area Planting (Code 342)*. http://www.nrcs.usda.gov/. 2002. Accessed 2007.

49. Bagette, Susan. NRCS, State Agronomist. Temple Texas. Interview 2007.

50. Pennsylvania State University. *Managing Turfgrass Diseases*. Department of Crop and Soil Sciences, Cooperative Extension, Pennsylvania State University. 2008. http://turfgrassmanagement.psu.edu/turfdis3.cfm. Accessed 2008.

51. Texas Parks and Wildlife Department. Texas Ecoregions. Available at http://www.tpwd.state.tx.us. 2007.

52. World Book. North America Climate: Texas. http://www.worldbook.com/wb/Students?content_spotlight/climates/north. Accessed 2007.

53. U.S. Environmental Protection Agency. http://www.epa.gov/region6/index.htm.

54. Google maps. http://maps.google.com/maps?f=s&utm_campaign=en&utm_source=en-ha-na-us-bk-gm&utm_medium=ha&utm_term=google%20maps. Accessed June 2009.

55. Tansley, A. G. and T. F. Chipp. "Aims and methods in the study of vegetation." *The British Empire Vegetation Committee and The Crown Agents for the Colonies.* London, UK. 1926.

56. SAS Institute. SAS/STAT users guide, Release 9.1. SAS Ins. Cary, North Carolina. 1988.

57. Federal Highway Administration. *Clear Zone and Horizontal Clearance*. http://www.fhwa.dot.gov/programadmin/clearzone.cfm. Accessed January 2011.

APPENDIX

EXPERIMENTAL SITE DATA

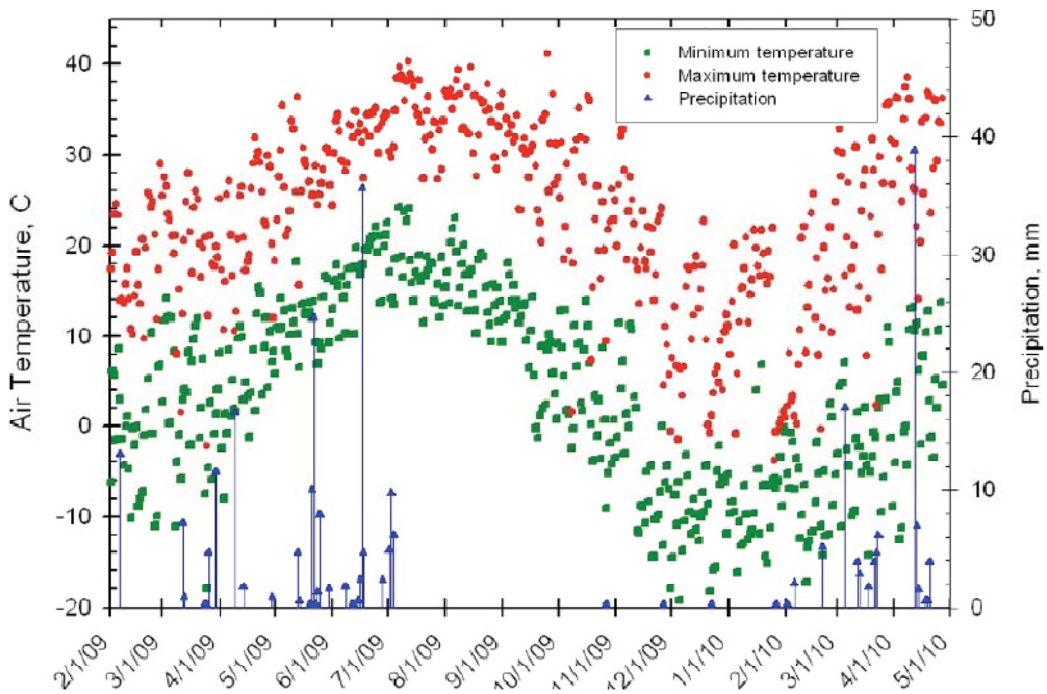


Figure 25. Ambient (max/min) Temperature and Precipitation, Adrian Site.

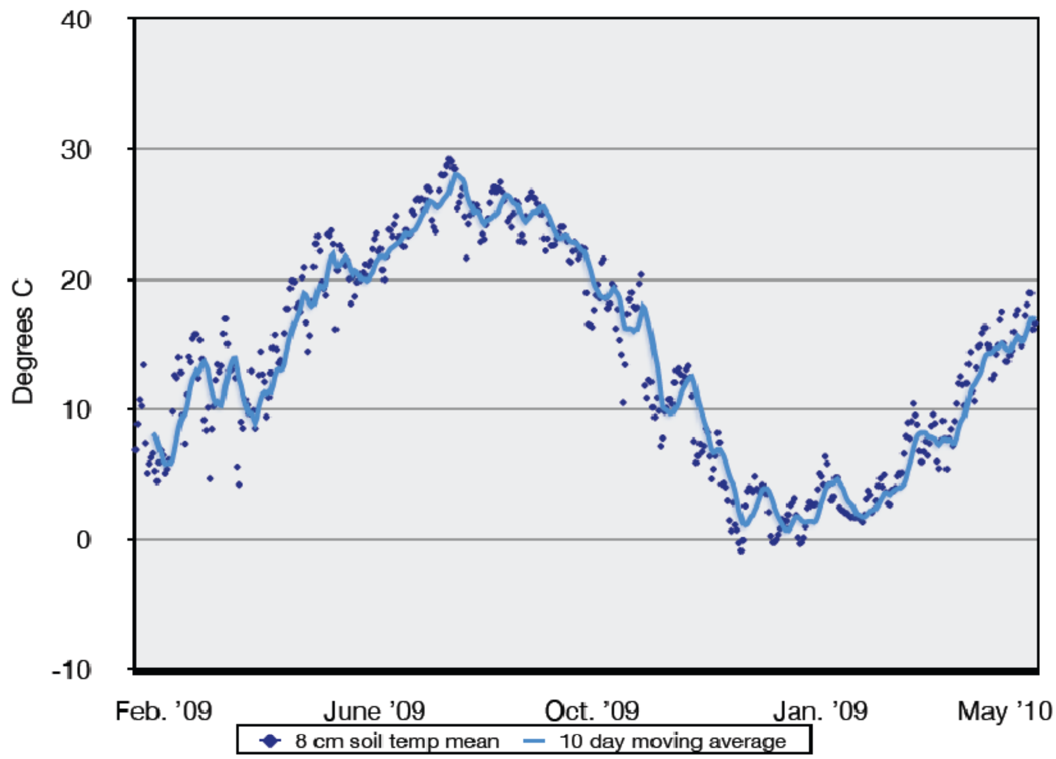


Figure 26. Soil Temperature Average at 3.15 Inches, Adrian Site

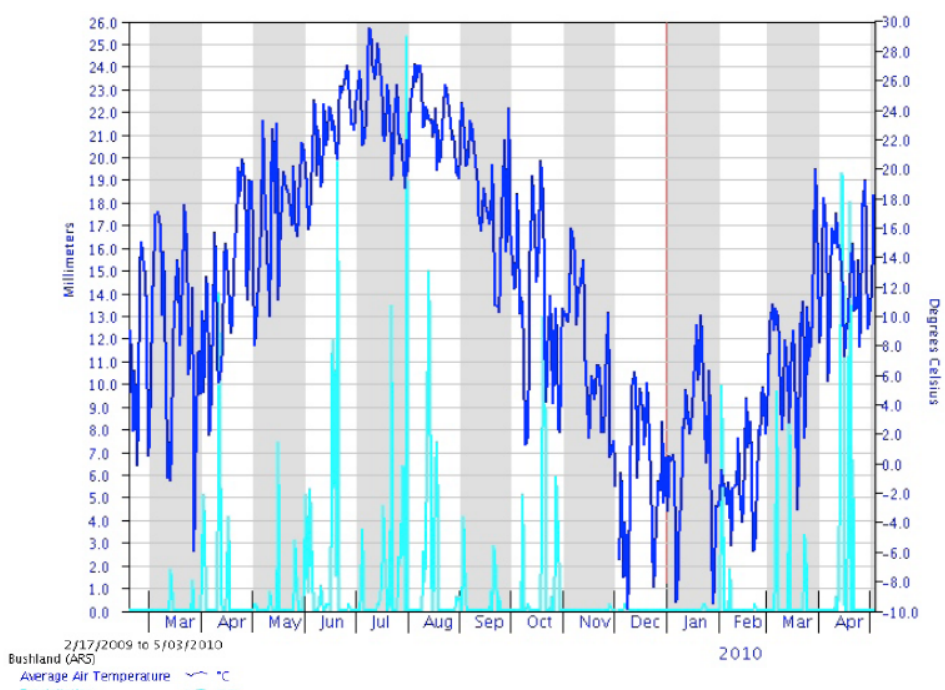


Figure 27. Daily Ambient Average Temperature and Precipitation, Bushland.

Figure 28. Soil Temperature (at 2 inches) Daily Average, Bushland.

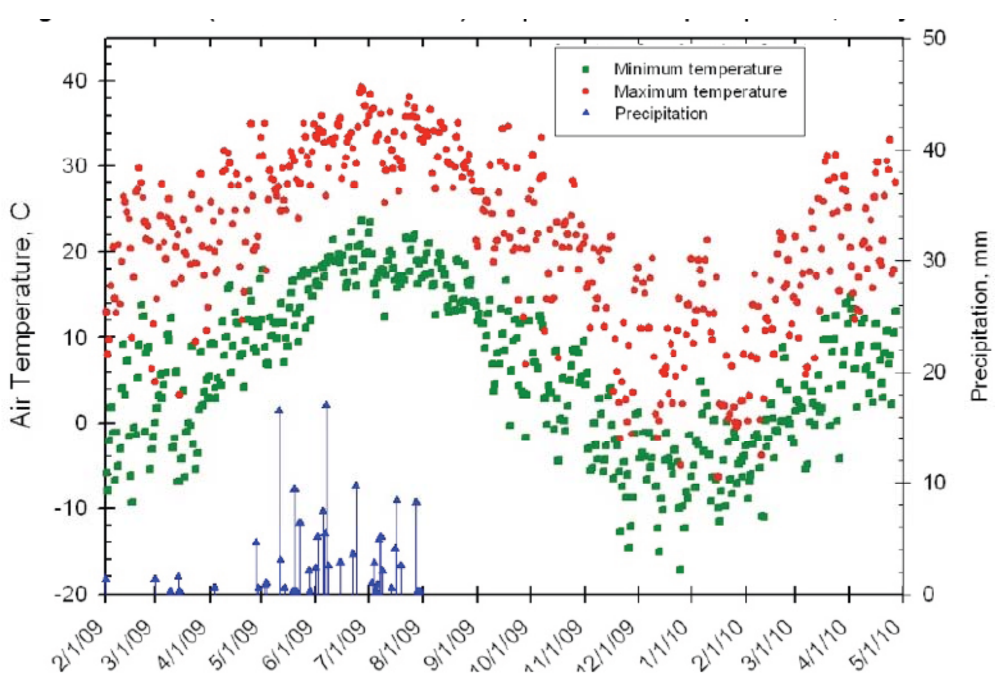


Figure 29. Ambient (max/min) Temperature and Precipitation, Canyon Site.

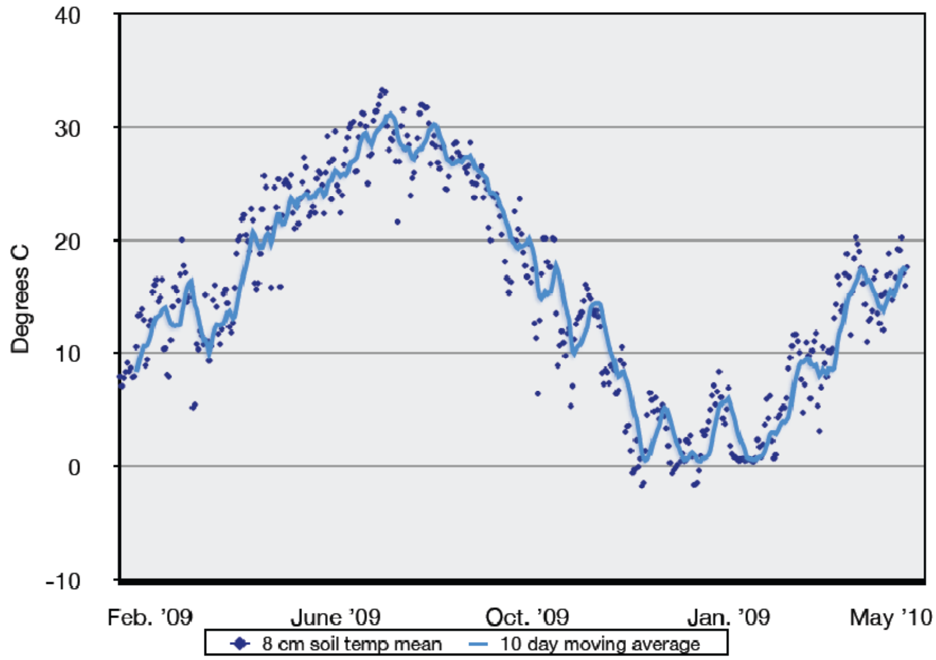


Figure 30. Average Daily Soil Temperature Canyon Site.

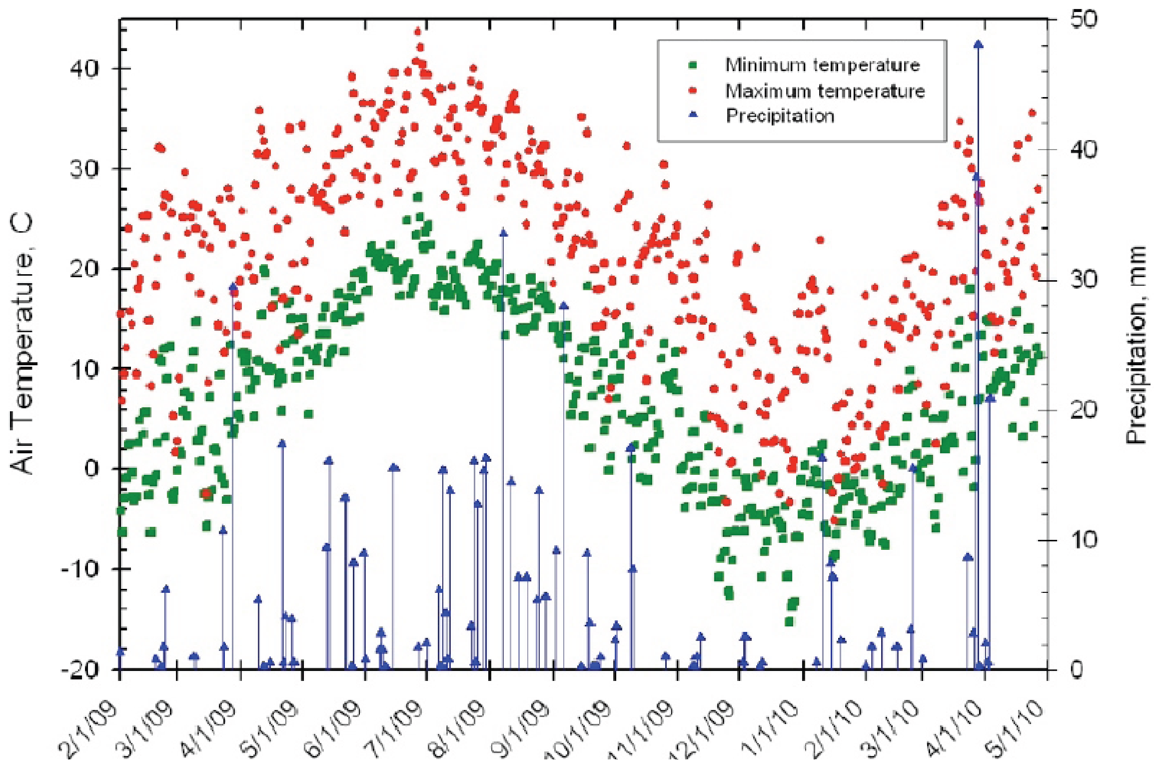


Figure 31. Ambient (max/min) Temperature and Precipitation, Lelia Lake Site.

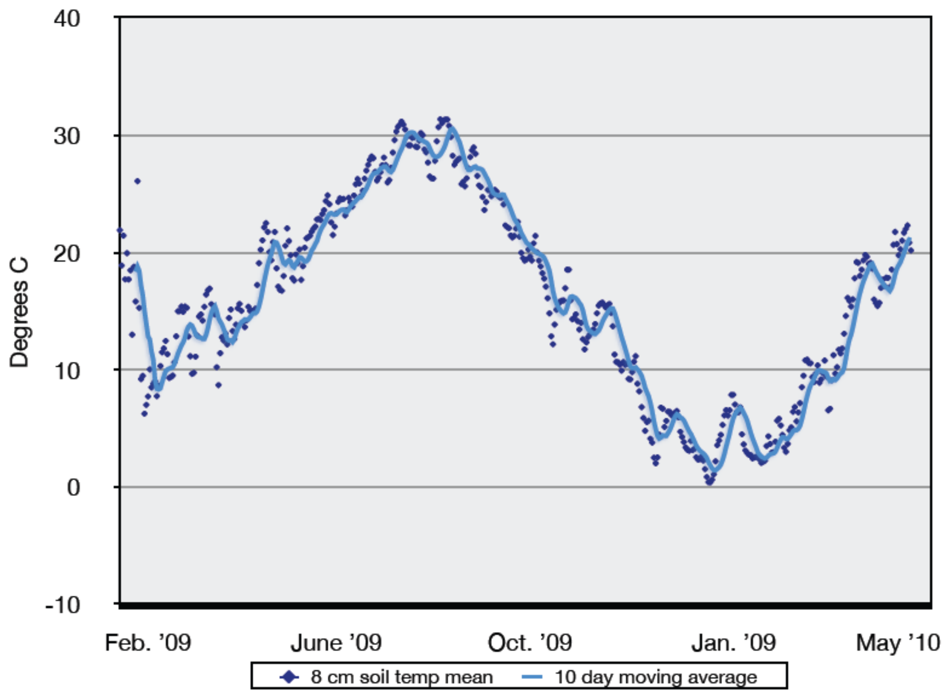


Figure 32. Average Daily Soil Temperature, Lelia Lake Site.