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16. Abstract

Several Texas Department of Transportation (TxDOT) districts have developed innovative landscape efforts specifically seeking to establish sustainable landscapes that require little if any supplemental water and utilize no chemical fertilizers. The concept behind this approach is that as land use intensifies, surface water runoff increases and the soil's ability to absorb runoff diminishes. TxDOT needs creative alternatives that can help soil retain moisture and recycle nutrients to reduce the energy expended in the maintenance of right-of-way landscape development. Techniques that utilize the environmental processes found in natural, self-sustaining, and self-sufficient plant communities have been clearly demonstrated to minimize and restore development impacts on soil, reduce peak storm flows, and increase infiltration. These techniques include major soil modifications as part of large-scale highway plantings. This project identifies many of the common non-chemical soil amendments and additives that can be used to create an environment that simulates a naturally occurring sustainable system found in undisturbed landscapes. Alternative management practices used by the public and private sectors were investigated for possible application to urban roadside landscapes for TxDOT and included cost and benefit evaluations, and the analysis of traditional and more sustainable landscaping comparisons of maintenance, water use, erosion control, and pollutant runoff mitigation. As these sustainable landscape development methods evolve, improved maintenance cost savings and public acceptance is anticipated.

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SYNTHESIS OF NEW METHODS FOR SUSTAINABLE ROADSIDE LANDSCAPES

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DISCLAIMER

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

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CHAPTER 1: INTRODUCTION

BACKGROUND

The Texas Department of Transportation (TxDOT) has one of the largest right-of-way areas in the nation with over 79,000 state maintained center-line miles of highway. Landscape development and aesthetic treatment in the urban areas are of particular concern for TxDOT. Urban centers such as Houston, Dallas–Fort Worth, San Antonio, and Austin will continue to lead the nation in population growth. At the same time, water resources and air quality issues will continue to concern city and state agencies. Many local, state, and federal agencies, as well as the private sector, have similar concerns about the protection and conservation of natural resources and are implementing new methods and approaches to achieve successful landscape development while conserving water and energy. This report evaluates alternative management practices by the public and private sectors for possible application to urban landscape projects for the Texas Department of Transportation.

Environmentally beneficial landscape development entails utilizing techniques that complement and enhance the local environment while minimizing the adverse effects of development. In particular, this means using regionally native plants and employing landscaping practices and technologies that conserve water and energy and reduce pollution. The maintenance of the right-of-way landscape is often constrained by state budgets. The ideal landscape planting for the highway roadside is one in which plant materials reach a state of maturity with minimal maintenance and only requires an overall long term management scheme.

Maintenance-free landscapes occur throughout nature. Native plant communities persist for long periods of time without interference or assistance from human maintenance of any kind. The specific mechanisms that make this possible evolved over many millennia, and some of these mechanisms may be used to create low maintenance landscapes near the roadside.

Most plants in nature rarely exist as isolated individuals. Typically plants are not suited to surviving on their own. They are more likely to thrive as plant communities or groups of plant species that have evolved together. Clusters of plants provide protection from weather and climate extremes for the group as a whole. Larger plants provide protection from winds and the sun for smaller, less tolerant plants. Smaller plants cover soil surfaces and provide important microclimates for insects, bacteria, fungi, and microbes. The entire community, including the soil, is supplied nutrients by the recycled leaves, limbs, and other debris. The *structures* of the plant and soil groups in nature are both the process and the result of this mutual dependency.

The interactions between plants in naturally occurring communities also include dependencies that are not immediately apparent. Insects that feed on one type of plant may pollinate others as well. One insect attracted to a particular plant species may prey on insects that are a problem to other plants. Some plants can exude very specialized chemicals that attract certain insects or repel other plants. Other plants become hosts to very specialized fungi on their roots that convert soil nutrients into a usable form, making them available to other plants in the community. In short, the underlying connections that make a natural plant community sustainable are highly evolved, highly complex, and very effective.

In many cases, plants that have evolved in these conditions cannot thrive (or even exist in some cases) alone outside of these communities. Plants taken out of this natural context may or may not survive in either roadside or ornamental settings. Depending on the species, most will not thrive even though they may not die. In almost all cases, some special accommodation must be made and maintained in order to replicate the critical conditions typically provided by their original habitat.

To be successful in roadside landscape management, it is necessary to choose the correct plant species, whether native or introduced, use soil amendments, and implement techniques that facilitate the natural re-establishment and maintenance of site-specific mycorrhizal fungi and associated soil microbes. Re-establishment of the mycorrhizal fungi, soil bacteria, and other beneficial soil organisms is an integral part of restoring highly disturbed soils. This can be accomplished through the incorporation of certain organic complexes such as humic acid, enzymes, and bacteria, along with rich, organic nutrients, such as compost. Such amendment will stimulate the growth of soil organisms in order to nourish and sustain vegetation.

Several TxDOT districts have developed innovative landscape efforts specifically to establish sustainable landscapes that require little if any supplemental water and utilize no chemical fertilizers. The concept behind this approach is that as land use intensifies, surface water runoff increases and the soil's ability to absorb runoff then diminishes. Intensified land use is a common situation in the urban environment and highlights the need for creative alternatives that can help reduce water runoff and increase groundwater infiltration. This is accomplished by utilizing the environmental processes that are the foundation for self-sustaining and self-sufficient plant communities found flourishing on their own outside the right-of-way. It has been clearly demonstrated that minimizing the impacts of development on native soils and forests, and restoring compacted soils, can reduce peak storm flows and increase infiltration. The Austin District first attempted this approach in 1993. Since then the Houston District has advanced this technique and greatly improved their success rate by experimenting with major soil modifications as part of the large-scale highway plantings and routine grass re-establishment on construction projects.

Field experience and research strongly suggest that a more natural approach to establishing self-sustaining plant communities within the urban roadway environment is both feasible and desirable and can provide long-term benefits. The advancement and further development of this approach will require a more comprehensive understanding of:

- the restoration of disturbed soils through suitable and cost-effective soil amendments,
- the use of integrated pest management (IPM) techniques (promote the least toxic approach to eliminating noxious weeds), and
- the practices for initial establishment and management of plant materials.

SUSTAINABLE LANDSCAPE TERMS

In order to better understand the natural approach to establishing self-sustaining plant communities, it is important to better define the meaning of many terms. This section will discuss a few of the terms that are commonly used in environmentally beneficial landscaping; more can be found in Appendix A.

The first term that requires definition is **natural landscaping**. This approach is often called native landscaping or even beneficial landscaping, and it emphasizes the use of native plants and natural materials. Natural landscaping can be defined as the practice of designing, cultivating, and maintaining plant communities that are native to a bioregion. Natural landscaping incorporates only minimal, if any, artificial methods of plant care such as chemical fertilizers, watering other than natural precipitation, weeding, and mowing.

The Environmental Protection Agency (EPA) states that the use of natural landscaping techniques provides numerous advantages over conventional and highly engineered site management techniques. Natural landscaping is based upon natural attributes and natural processes, which result in:

- reduced landscape installation and maintenance costs,
- avoidance of the use of lawn chemicals such as fertilizers and herbicides,
- reduced or eliminated costs for irrigation systems,
- improved habitat and increased biodiversity,
- distinctive and attractive sites,
- improved water quality and reduced damages from storm water,
- improved outdoor recreation and education opportunities, and
- strengthened stewardship of the environment by people *(2)*.

Another term used frequently is **sustainable landscaping.** The word "sustain" comes from the Latin *sustinere* (*sus*- meaning "from below" and *tenere* meaning "to hold"), to keep in existence or maintain, and implies long-term support or permanence. *Webster's New Collegiate Dictionary* defines "sustainable" as the ability to sustain or carry or withstand the weight of pressure *(3)*. As it pertains to agriculture, "sustainable" describes farming systems that are "capable of maintaining their productivity and usefulness to society indefinitely. Such systems must be resource-conserving, socially supportive, commercially competitive, and environmentally sound" (*4*).

Therefore, strictly speaking, a sustainable landscape would be able to carry or withstand the pressure placed on it by the surrounding environment. This strict definition is carried out by the definition used by the Colorado State Cooperative Extension Horticulture, which states that sustainable landscaping should include an attractive environment that is in balance with the local climate and requires minimal resource inputs, such as fertilizer, pesticides, and water (*5*).

As defined for this project, a successful sustainable roadside landscape should possess the following features:

- require low energy inputs including maintenance and amendments,
- have low chemical dependence,
- have a cost-effective method of implementation, and
- be as aesthetically pleasing as a natural landscape.

A sustainable landscape for roadsides can be thought of as an "urban forest or grassland" that consists of plant life that requires little to no maintenance and coexists with modern transportation systems. On the other hand, non-sustainable landscaping often requires either intense maintenance or resources. Non-sustainable landscaping may feature either native or non-native plants that require an inordinate amount of care and water to survive or remain viable.

The word **organic** is another term that has multiple meanings and connotations. The definition of organic to chemists refers to materials built with carbon structures. This definition often causes confusion in the discussion of organic agriculture. **Organic agriculture** is a system of farming that does not use synthetic (i.e., artificially produced) pesticides or fertilizers and that emphasizes soil health and natural cycles. As organic agriculture developed as a system of farming, and consequently as a method of marketing for the produce grown in that system, federal regulations were developed to define organic farming. However, there are no regulations that define organic land care or landscaping. The generally accepted definition of organic land care and landscaping states that as in organic agriculture, no synthetic pesticides, fertilizers, or soil amendments are used, and land care practices take into account the local ecosystem, benefiting the web of life.

Traditional landscaping is an attempt to create a landscape that looks a certain way regardless of location. One example is a heavily manicured roadside or lawn that has a mono-culture stand of turf and bedding plants. Traditional landscaping often relies heavily on ornamentals. Ornamentals are defined as shrubs or small trees grown for a decorative effect. Although often associated with non-native or transplanted shrubberies that are inserted into the landscape to achieve a desired effect, ornamentals can be native shrubs used in a naturalized approach to landscaping. The use of non-native ornamentals in a traditional landscape setting often requires the use of chemicals for the plant to thrive and produce the desired effect. Chemicals used in landscaping include herbicides, pesticides, fungicides, fertilizers, aquacides, and other non-natural treatments. The chemicals are used to amend the soils, provide nutrients, and kill insects and diseases. Non-chemical alternatives may also be used. Examples of non-chemical methods include composting, beneficial insects, companion plantings, and use of disease resistant native plants.

PROJECT GOAL AND OBJECTIVES

The primary goal of the project was to investigate innovative management practices by the public and private sectors for possible application to urban landscape projects for the Texas Department of Transportation. This goal was accomplished through the following three specific objectives:

- Investigate current practices for sustainable roadside landscapes in Texas and other states.
- Estimate the benefits (including environmental, financial, and public) of sustainable roadside landscape programs for TxDOT.
- Evaluate the feasibility of implementing sustainable roadside landscape programs for TxDOT with a focus on maintenance, water use, erosion control, and pollutant runoff mitigation.

This project also sought to analyze the current practice of plant community establishment and to identify the issues resulting in successful and less than successful projects. The research team conducted a thorough investigation into the current technologies, processes, and products that may be suitable for use in establishing improved vegetation through soil restoration. The research team examined reports issued by other departments of transportation (DOTs), commercial developers, corporate campuses, and other agencies. The team attempted to identify practices, products, and procedures that were most likely to result in successful roadside landscape development while recognizing and providing the general diversity required by the vast climatic and vegetative ranges found in Texas.

WORK PLAN

The work plan for the project consisted of a number of significant tasks. A brief synopsis of the tasks and work conducted is given below.

Task 1. Literature Review for Sustainable Roadside Landscapes

A comprehensive literature search was conducted to identify publications and recent studies on sustainable landscapes, their effects on the economy, and other economic implications associated with sustainable landscapes in urban locations. Key words and key word combinations selected for the search included: sustainable landscaping, environmental landscaping, xeriscaping, minimum input landscaping, using native plants, natural landscaping, ecological landscaping, IPM techniques, self-sustaining plants, soil restoration, natural plant management, green building process, self-sustaining plant communities, reclamation, and runoff control. Potential literature sources were identified, acquired, and reviewed for applicability to the project.

Task 2. Collection of Detailed Information on the State of the Practice of Sustainable Roadside Landscaping

The project team then developed a detailed plan to assess innovative practices of sustainable roadside landscaping identified by the literature review. This assessment included personal interviews and assembling relevant follow-on documents and reports. Significant issues considered in the assessment included: aspects of cost, sustainability, management practices, soil amendment methods, water use, erosion control, and pollutant runoff mitigation. The research team focused on not only what technologies are used to implement these strategies and techniques, but also information on success rates, efficiency, and benefits that may result from their implementation. The team attempted to assess how these systems would fit into the overall structure of the roadside landscape management. The research team also attempted to identify and specify any documentation that contained concepts of operations and maintenance, as well as information about when and where to implement these landscape strategies.

Task 3. Evaluation of the Information Relevant to Sustainable Roadside Landscaping and the Landscaping Technologies Applicable for TxDOT and Its Ecological Zones

Information collected from the professional, private, and public sources was evaluated and processed relative to experiences and related climatic considerations for this project for TxDOT. In some cases, some techniques successfully applied in zones where 50 to 60 inches of rainfall occurs every year may not be applicable for this evaluation. However, some of these techniques may still be relevant for application in the far eastern area of the state.

Task 4. Analysis of Results and Creation of a Comparison Document

Information gathered in the case studies examination was combined with other relevant information obtained during this project, and a comparison document was drafted. This document contains a matrix of the elements of both natural and sustainable landscaping practices.

Task 5. Prepare Final Project Reports of Research Findings

The results of this investigation are summarized in this technical report, which details the economic and environmental benefits to TxDOT if natural or sustainable landscaping is pursued.

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CHAPTER 2:
CONFLICT ON THE ROADSIDE—HIGHWAY VERSUS VEGETATION

According to Mark Hieber in *Land Development Today*:

> The increasing pace of urbanization has completely changed the natural systems that have governed the landscape for thousands of years. Along with deforestation, topsoil that supports native species has been stripped. The remaining subsoils have been compacted to such densities that their storm water infiltration capacity is reduced to the equivalent of pavement. Surfaces have been sealed with asphalt and concrete, often leaving only token remnants of green spaces within which we place one or two orderly, lollipop shaped trees with some turfgrass beneath. The incredible diversity of our native plants has been traded for a few sterile, imported species of trees and shrubs. And to date, we've considered this to be "progress" and we've called this "not too bad" (*1*).

HIGHWAY CONSTRUCTION AND SOILS

Whether one is constructing an eight-lane freeway or a sustainable roadside landscape, success begins with the proper soil foundation. Each of these conditions requires a different soil for success. Soil has many intrinsic functions and values. According to the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS), soil has five basic and essential functions:

1. regulating storm water through overland flow and soil infiltration;
2. sustaining plant and animal life;
3. filtering potential pollutants;
4. cycling nutrients; and
5. supporting structures, such as highways (*2*).

Unfortunately, the functions of sustaining plant life and supporting structures often come into direct conflict since their inherent and ideal soil properties generally differ.

The roadway, embankments, and surrounding residual right-of-way are extremely manipulated and highly disturbed soils. From a roadway engineering perspective, this road base and the embankment (TxDOT Standard Specification Item 132 Embankment) should be compacted to between 95 percent and 98 percent, depending on the plasticity index (PI) of the soil (*3*). This compaction increases the bulk density of the soil by reducing the amount of pore space. This pore space consists of the air and water in the soil and is normally about 50 percent of the soil, as shown in Figure 2.1. These embankments are constructed in layers to ensure compaction is uniform and that the embankments meet the requirements for field density and moisture content according to the plans and specifications for the site. Embankments and roadbeds are the soil structures that support the highway. These same embankments are also one of the key areas used in roadside landscape development in urban settings, ergo the conflict. Other landscape opportunities are situated at interchanges and sporadic locations where right-of-way allows. In urban locations, many of these consist of narrow areas adjacent to retaining walls or in medians. In conjunction with highly disturbed soils, urban locations also have multiple underground utilities and other infrastructure, all of which have had their own construction site impacts. This highly disturbed soil is subject to the heat generated by the surrounding pavements and emissions produced by traffic, all of which can adversely affect the biological processes of the adjacent soil and vegetation.

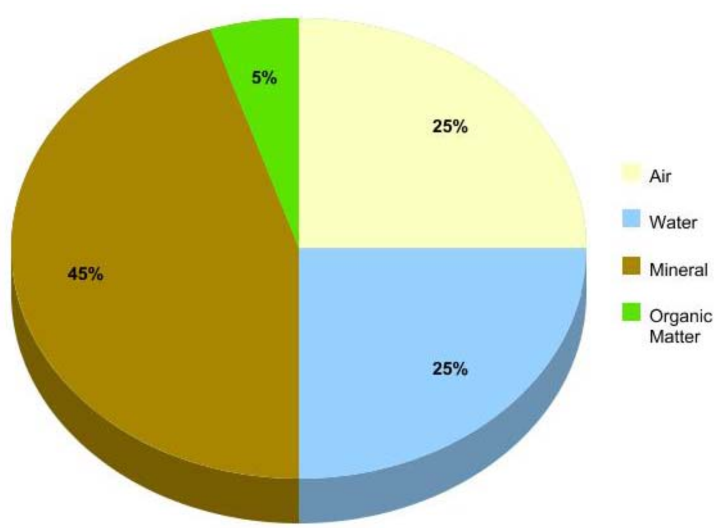

Figure 2.1. Percentage of Pore Space in a Typical Soil.

Included in the impacts to the soils, and ultimately the vegetation, are the scale of highway construction and the duration of the construction period. These construction projects can impact many miles at one time, usually traverse multiple watersheds or drainage areas, and can last several years. Within these linear projects lie many construction staging and materials storage areas. In urban situations, the larger right-of-way areas within interchanges are often used for material stockpiles, equipment storage, and servicing, as shown in Figure 2.2.

Figure 2.2. Typical Right-of-Way Construction Areas.

This activity contributes to the compaction of the soil and to the potential for pollutants, such as petroleum products, lime, and other construction material additives, to remain in the soil after construction. The residual soil has properties that require enhancement to provide a suitable environment for plant growth. Some indicators of soil quality lie in the physical, chemical, and biological relationships, as shown in Table 2.1. Hence, efforts are needed to rehabilitate the soil or planting medium to ensure that vegetation is given an environment that will facilitate and sustain its growth on the roadside.

Table 2.1. Soil Quality Indicators (Adapted from NRCS [*2*]).

Indicator		Relationship to Soil Health
Soil structure, depth, infiltration, bulk density, water holding capacity	**Physical**	Water and nutrient retention and transport, microbe habitat, compaction, water movement, porosity, workability
pH, electrical conductivity, extractable N-P-K* (*nitrogen-phosphorus-potassium)	**Chemical**	Biological and chemical activity thresholds, plant and microbe activity thresholds, plant available nutrients, potential for N and P loss
Microbial biomass C* and N, potentially mineralizeable N, soil respiration (*carbon)	**Biological**	Microbial catalytic potential and repository for C and N, soil productivity and N supplying potential, microbial activity measure
Soil organic matter		Soil fertility, structure, stability, nutrient retention, soil erosion

REHABILITATING THE SOIL

A significant deficiency in compacted roadway soils is a lack of soil organic matter and microbial biomass. The focus on organic matter soil amendments is fundamental. Organic matter affects critical soil functions and can be manipulated by practices at the soil's surface. So, the questions that must be addressed are: what is organic matter and why does post-construction soil need to be amended with these substances to become a sustainable environment? According to the Soil Quality Institute:

> Soil organic matter is carbon-rich material that includes plant, animal, and microbial residue in various stages of decomposition. Live soil organisms and plant roots are part of the carbon pool in soil but are not considered soil organic matter until they die and begin to decay. The quantity and composition of soil organic matter vary significantly among major ecosystems. Soil in arid, semiarid, and hot, humid regions commonly has less organic matter than soil in other environments (*4*).

According to Cooperband in *Building Soil Organic Matter with Organic Amendments* and NCRS, organic matter is an essential component of soils because it:

- provides a carbon and energy source for soil microbes;
- aids plant growth by improving the soil's ability to store and transmit air and water as measured by improved porosity, water holding capacity, and drought resistance;

- enhances soil fertility and plant productivity by improving the ability of the soil to store and supply nutrients, water, and air;
- increases cation-exchange and anion-exchange capacities;
- binds soil particles together into stable aggregates, thus improving porosity, infiltration, and root penetration and reducing compaction, runoff, and erosion;
- sequesters carbon from the atmosphere;
- reduces the negative environmental effects of pesticides, heavy metals, and other pollutants by chemically binding contaminants; and
- has the additional benefits of:
  - reducing disease and insects,
  - reducing site energy input and maintenance, and
  - creating a replenishing system (*5*, *6*).

Post-construction soils, especially roadside soils, have a greatly reduced percentage of organic matter because these construction soils are usually taken from soil sub-horizon locations or those soil layers that are below the topsoil. These subsoils typically have the most favorable engineering qualities. Organic matter in the soil conflicts with the engineering properties necessary to support a road bed or embankment, as do the pore spaces, which contain air and water. Typical undisturbed, natural or pre-construction soil structure contains organic matter ranging from 1 percent to 5 percent (see Figure 2.1), depending on location. NCRS classifies typical soil horizons as shown in Figure 2.3. These horizons, from top to bottom, are:

- O—organic: litter layer consisting of leaves, twigs, roots, and other relatively un-decomposed organic material on the surface of the soil;
- A—topsoil or surface soil: most productive soil horizon comprised of mineral soil with the highest accumulation of organic matter;
- B—subsoil: usually light colored, dense, and low in organic matter;
- C—substratum or parent material: unconsolidated parent mineral material; and
- R (below C, not shown in figure)—bedrock: solid rock that underlies the soil and other unconsolidated material (*2*).

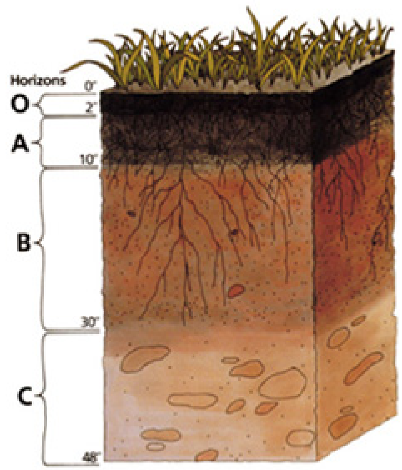

Figure 2.3. NRCS Soil Horizons (*2*).

A major benefit found throughout the literature associated with organic matter and soil structure is the ability of organic matter to reduce the erodability of soil. Soil erodability is based upon the soil's ability to resist particle detachment. Soils with a greater infiltration rate, higher percentages of organic matter content, and improved soil structure have a lower erodability (*7*). Soil texture is the percentage of the soil in terms of particle distribution of sand, silt, and clay (see Figure 2.4). Soil texture affects the structure, water holding capacity, nutrient holding capacity, aeration, drainage, and root penetration and growth. However, soil structure defines how these particles are both chemically and biologically held together. Organic matter is a major binding agent within the soil structure. Stable soil aggregates resist erosion. This aggregation occurs when the microbes in the organic matter release polysaccharides, or long-chain sugars. According to Cooperband, "These polysaccharides promote formation of large or macro-aggregates. As the organic matter decomposes over the longer term, different sizes of aggregates are formed that are resistant to physical disruption. The number and diversity of stable soil aggregates are what give a soil an excellent physical structure" (*5*).

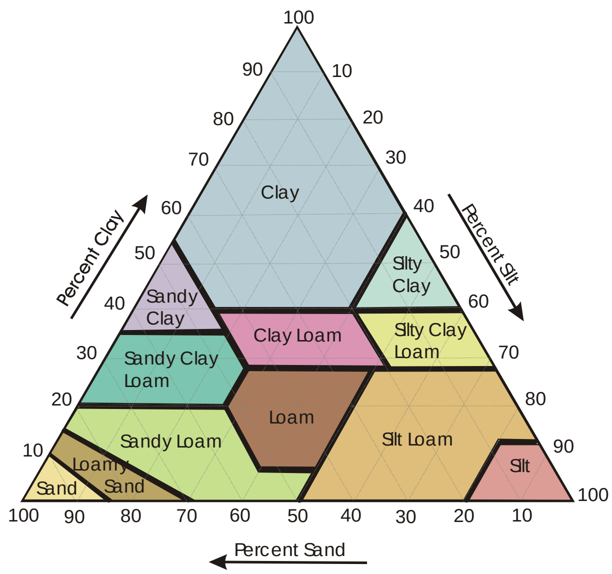

Figure 2.4. Soil Triangle.

Soil erosion can be reduced by the application of compost to the soil surface. The initial TxDOT compost research done in 1995 by Storey et al. confirms that surface application of compost effectively reduced sediment loss and produced vigorous vegetation (*8*). Subsequent TxDOT research by Storey et al. (*9*) and Kirchhoff et al. (*10*) revealed not only the benefits of using organic amendments such as compost but alleviated some of the water quality concerns of using organics in the right-of-way. The leachate from the composts used in the study did not warrant concern to receiving waters unless in an environmentally sensitive area (*9, 10*).

Soil Nutrients

These disturbed or post-construction soil qualities are not very conducive to plant establishment, growth, and sustainability. For plants to establish, grow, and sustain, they need mineral nutrients. These mineral nutrients are classified as macro- or micronutrients. The nine macronutrients are found in greater quantities in the soil than the eight micronutrients and are shown in Table 2.2. More information on macro- and micronutrients and organic sources can be found in Appendix D.

Table 2.2. Macro- and Micronutrients (*11*).

Macronutrients	Micronutrients
Calcium – Ca	Boron – B
Carbon – C	Chlorine – Cl
Hydrogen – H	Cobalt – Co
Magnesium – Mg	Copper – Cu
Nitrogen – N	Iron – Fe
Oxygen – O	Manganese – Mn
Phosphorus – P	Molybdenum – Mo
Potassium – K	Zinc - Zn
Sulfur - S	

These macro- and micronutrients are components of the organics in the soil that establish and maintain a system that can regenerate nutrients for vegetation and provide low energy input through increased resistance to erosion, drought, and pests. "The U.S. Environmental Protection Agency's (EPA's) GreenScapes program provides cost-efficient and environmentally friendly solutions for landscaping. Designed to help preserve natural resources and prevent waste and pollution, GreenScapes encourages companies, government agencies, other entities, and homeowners to make more holistic decisions regarding waste generation and disposal and the associated impacts on land, water, air, and energy use" (*12*). The EPA's GreenScapes program recommends the use of biobased products that are composed of biological, agricultural (plant, animal, or marine), or forestry materials. According to the EPA, these products are often less harmful to the environment, and many products such as compost and other fertilizers can be found made from biobased materials (*12*). Other amendments include microbes such as bacteria and fungi. The major role of the bacteria and fungi is to decompose organic materials in the soil, including microorganisms and roots. This turnover of root tissues and microbial cells releases organically bound N and P as plant available, inorganic ("mineral") forms, or the process referred to as mineralization. Organic additives and amendments have differing mineralization rates. Some mineralize quickly and release all of their nutrients in the first one to four months (growing season). Others have a slow mineralization rate and release portions of their nutrients over several years and may be considered soil building materials (*13*).

The primary benefit of this decomposition is to provide substrate for more microbial cells and humus (recalcitrant, stable organic matter). Most of this activity occurs in the rhizosphere, or area immediately surrounding the roots. The reason for this is that roots are a source of carbon or food for the microbes *(14)*. Soil and plants inoculated with mycorrhyzae or other fungi have an increased root area, which assists with water and nutrient uptake and may make the plant more drought resistant.

One of the concerns for use of organic matter in the soil is longevity. How long do the amendments last and how often, if ever, do these need to be reapplied? The first thing to realize is the cycle that comes with a sustainable landscape system. Environmental factors, such as rainfall and temperature, interact over time to affect the amount of organic matter in soil. Increasing levels of organic matter promote a higher water-holding capacity. This results in increased plant growth and available litter, thereby adding to the quantity and rates of decomposition. As stated earlier, roots are the primary source of organic matter; as the plants thrive, more roots are made available. Dead roots and gelatinous materials exuded by plant roots as they grow through the soil are decomposed by soil organisms and converted into organic matter. This makes root production important.

Having a system in place that will perpetuate this process is vital. Soil organisms break down litter, dead roots, and organic matter into smaller fragments; convert nutrients into plant available forms; and release carbon dioxide into the atmosphere. Decomposition rates are highest in warm, moist soils *(4)*.

So does this mean that one should only use organic fertilizers? Not necessarily. As far as nutrient uptake by plant materials is concerned, the plant does not distinguish between an organic or inorganic source. The root can absorb only nutrients that have been broken down into water soluble forms. It makes no difference if the atom of nitrogen the plant is absorbing comes from compost or a bag of fertilizer. However, there are advantages and disadvantages to each form of fertilizer, organic and inorganic *(15)*. Over application of fertilizer can be problematic because fertilizers are often surface applied, and the quantities not utilized by plants are suspended in storm water runoff and sent downstream to receiving water bodies. Chapter 3 provides more information on these processes. In addition, inorganic fertilizers do not significantly change the soil's characteristics such as aggregation, water availability, and compaction reduction as do organic amendments.

There are copious organic additives and amendments available, and many are listed in Appendices B and C with their product components, typical nutrient analysis, release time, advantages, disadvantages, and typical application rates.

WATER QUALITY CONFLICTS

From a water quality perspective, these compacted, inorganic soils have a negative impact by contributing to increased storm water runoff by reducing infiltration and groundwater recharge quantities, and making more water available for evaporation. With highway construction soils, not only are the storm water functions (water storage and cleansing) of the soils compromised, but many of the landscaped roadsides may actually generate pollutants by requiring additional irrigation and chemical fertilization to establish and sustain plant material in the harsh roadside conditions. The goal of a sustainable landscape is to provide a low energy input landscape that reduces the impacts usually associated with standard or traditional practices.

Development of a sustainable roadside landscape should also help with the storm water management function of that landscape. A good soil structure with healthy plant materials can help reduce runoff quantities through plant uptake of water or evapotranspiration (evaporation and transpiration). Evaporation is the loss from open bodies of water, such as lakes and reservoirs, wetlands, bare soil, and snow cover; while transpiration is the loss from living plant surfaces (*16*).

Other benefits from these materials can include the ability of organic amendments such as compost to remove runoff pollutants. The EPA, the Texas Commission on Environmental Quality (TCEQ), and the Federal Highway Administration recognize the bioremediation capabilities of compost:

Compost bioremediation refers to the use of a biological system of microorganisms in a mature, cured compost to sequester or break down contaminants in water or soil. Microorganisms consume contaminants in soils, ground and surface waters, and air. The contaminants are digested, metabolized, and transformed into humus and inert byproducts, such as carbon dioxide, water, and salts. Compost bioremediation has proven effective in degrading or altering many types of contaminants, such as chlorinated and non-chlorinated hydrocarbons, wood-preserving chemicals, solvents, heavy metals, pesticides, petroleum products, and explosives. Compost used in bioremediation is referred to as "tailored" or "designed" compost in that it is specially made to treat specific contaminants at specific sites. (*17*)

Reducing surface runoff is usually accomplished by changing the soil's physical, chemical, and biological properties. According to NRCS, "Compost is an organic matter resource that has the unique ability to improve the chemical, physical, and biological characteristics of soil or growing media. Compost contains many different organisms which are active at different times and interact with one another, with plants, and with the soil. The combined result includes a number of beneficial functions, including nutrient cycling, moderated water flow, and pest control" (*2*). For TxDOT, compost is the most widely used organic soil amendment. TxDOT has sponsored several studies regarding compost and compost use. Data from research done by Kirchhoff et al. (*18*) demonstrated that the soil's moisture retention capabilities did increase and that the increase is much greater in the sandy soils blended with compost than in the clay/compost soil blends. The clay blends retained much more moisture overall than did the sand blends; however, amended sandy soil had the greatest percentage increase in moisture retention capabilities (*18*). King (*19*) also states that the susceptibility of a soil to either erode or retain storm water is determined by the soil's organic matter content as well as its particle size, structure, and permeability. The addition of organic matter, through compost amendments, changes the structure and permeability of the soil. Drainage and aeration are then both increased. However, King is uncertain as to the longevity of the effects of organic matter amendments in terms of permeability (*19*).

The most important system for storing water in the soil structure is organic matter. Its ability to retain moisture enables it to also retain nutrients and make them available for use by the plants. In addition, microorganisms rely upon soil rich in organic matter to survive and perform their essential functions within the soil-plant community. These microbes actively decompose leaf litter and other organic debris. The organic matter also chemically binds many runoff pollutants, allowing microbes to biologically reduce many of these toxins.

IMPACTS OF HEALTHY VEGETATION

Vegetation, especially trees, not only reduces runoff quantities, it also has the ability to utilize and thereby remove the greenhouse gas carbon dioxide, CO_2. This atmospheric removal of CO_2 is called carbon sequestration in landform or terrestrial conditions. Not only is this gas removed, but it can also be stored in what are called carbon sinks. These storage areas can be aboveground, as in trees or in the living biomass of the soil which contains roots and microorganisms such as bacteria and fungi. The storage of the CO_2 gas is an important component of the sequestration cycle. It is not enough to just remove the gas through plant uptake; this carbon needs to remain or be fixed into a carbon pool or sink in order to have an impact on the atmosphere. Establishment of a landscape that has a sustainable organic soil structure will assist in the ability of the plant to absorb and retain the CO_2. According to the U.S. Department of Energy, “It is important to remember that while many processes occur at the molecular level (i.e., photosynthesis, formation and protection of soil organic matter, etc.); management practices to enhance carbon sequestration will be implemented at the landscape scale. At this scale, ecosystems are the key functional units for estimating productivity and carbon sequestration” (*20*).

So, how does that relate to air pollution? According to the North Carolina State University Cooperative Extension, one healthy tree can store about 13 pounds of carbon each year. An acre of mature trees will retain about 2.6 tons of carbon dioxide annually. In relation to the quantities of fuel consumed, a gallon of burned gasoline will produce about 20 pounds of carbon dioxide. So, it will take seven trees to remove the CO_2 produced for every 10,000 miles driven in a vehicle that gets 40 miles per gallon (mpg) of gasoline. In a vehicle that only gets 12 mpg, it will take up to 25 trees to accomplish the same carbon sequestering (*21*).

But trees do not just absorb the carbon dioxide and other deleterious gasses such as sulfur dioxide, ozone, chlorine, nitrous dioxide, fluorine, and peroxyacetylnitrate (PAN); they produce oxygen as a byproduct of their photosynthesis process. Air particulates are also removed by trees in the urban environment. Dust, pollen, and smoke can also be reduced by the presence of trees, especially in the urban environment. However, continued exposure and absorption of these pollutants can contribute to plant decline by interfering with plant processes *(22)*.

Photosynthesis is probably one of the most important of these biochemical plant processes. It is the process responsible for producing atmospheric oxygen. Photosynthesis converts the energy from light into simple sugars that are then converted to glucose, the major food molecule of the cell. A simplified general equation for photosynthesis is *(22)*:

$$6CO_2 + 12\ H_20 + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Carbon Dioxide + Water + Light Energy → Glucose + Oxygen + Water

This process is important because, for every six molecules of carbon dioxide and twelve molecules of water, the process will produce one molecule of sugar, six molecules of oxygen, and six molecules of water. Keeping the plants in a sustainable environment can help maintain plant health, thereby enhancing the plant process performance.

In terms of how much of a cost benefit an urban forest represents, in the article "Greenbacks in the Greenery," Catherine Benotto states, "In the Puget Sound region, trees remove 78 million pounds of pollutants per year. This represents a value of $19.5 million if the air were cleaned by industrial means" *(23)*. Another study by the USDA Center for Urban Forest Research at the Pacific Southwest Research Station estimated that approximately 1457 metric tons of air pollutants were removed by the 6 million trees through plant processes annually. The cost benefit to the public included the heating and cooling benefits that trees represent or their ability to mitigate the temperature of structures and surrounding pavements *(24)*.

The solution for the conflict on the roadside between highly disturbed soils and sustainable landscape development involves the rehabilitation of the soil with organic matter to gain maximum benefit from the soil, and vegetation as they perform their roles as erosion control, biofiltration, carbon sequestration, and storage for nutrients, water, and air.

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CHAPTER 3:
SOIL AMENDMENTS AND FERTILIZERS

This chapter describes naturally derived soil amendments. The first section of this chapter provides some background information on the serious challenges facing Texas and the United States to improve water quality in urban watersheds. It also clarifies the definition of natural amendments and their capabilities and limitations. The breakdown and transport of these unique materials and their release of nutrients are also described and compared to synthetic chemical treatments. The behavior of these natural materials, not surprisingly, can serve to reduce runoff and pollutant transport because of their structure, composition, and biodegradation rates.

SOIL AMENDMENTS AND IMPACTS TO WATER QUALITY

A **soil amendment** is any material that can be mixed into a soil for a specific purpose. These amendments may be inorganic (non-carbon-based) or organic (largely carbon-based). An amendment does not necessarily break down to provide nutrients or compounds for plant health. In contrast, by law, a fertilizer guarantees that a certain percentage of available nutrients designed to promote vegetation growth are present in the mixture. These percentages must be proclaimed on the product. An organic fertilizer, which is derived from natural source materials, will also guarantee a certain percentage of nutrients, but the percentages are usually much lower than manufactured chemical fertilizers and may be less available to the vegetation over time (slower release). Many organizations and public utilities are moving away from manufactured concentrated nutrient soil amendments (considered "chemical" additives) toward more natural "non-chemical" forms of natural materials such as compost and mulch. Chapter 5 will further address the shift to the use of large scale sustainable landscapes.

The cost to the nation and the states due to the overuse of some chemical soil amendments and fertilizers has been substantial. To protect against the deterioration of the nation's water bodies, the U.S. Congress enacted amendments to the Clean Water Act to implement the Total Maximum Daily Load (TMDL) program in conjunction with the states. The TMDL program has been designed to improve water quality in impaired or threatened water bodies in all the states. It was created to fulfill the requirements of Section 303(d), which focuses on water impairments under the Clean Water Act. A major goal of the program is for the states to design programs to restore the full use of a water body that has experienced a limitation in its potential for use of one or more of its original intended uses. Stakeholders must work with state agencies to develop implementation plans to reduce man-made sources of pollution and gradually restore the water bodies within the watershed (*1*). With such extensive urbanization in Central and South Texas, almost every watershed in Texas has been under some consideration for a TMDL program. The cost to the nation for TMDL appropriations to develop these plans will approach $1 billion over the next 10 to 15 years (*2*). These totals do not include matching requirements that the federal government typically requires from the states to implement these initiatives, which is often 40 percent of the total project cost. This could add an additional $400 million to the project costs, and the costs of monitoring to develop these plans will probably cost another $300 million over the same period, nearly reaching an approximate $2 billion price tag just to implement the plans and monitor water quality for the impaired rivers and streams. The U.S. EPA is currently reviewing overall TMDL program costs, but it is certain that the implementation costs are not being reduced since more impaired water bodies are being identified and restoration costs are increasing.

Water body impairment classification typically falls under four broad categories—low dissolved oxygen, pathogens or bacterial impairment, and herbicides and pesticides contamination. Excessive runoff from overuse of fertilizers (nutrients) and/or pesticides and herbicides can cause elevated levels of contaminants, causing water body impairment. A key consequence of excessive nitrate and phosphorous pollution is the condition of **eutrophication** of streams and water bodies. This condition takes place when excessive algal growth consumes oxygen and depletes the oxygen saturation of the receiving waters to the point at which fish kills can occur. While soluble nitrate runoff from excessive fertilizer use is well known to cause water quality impairments, phosphorous enrichment typically occurs due to excessive soil erosion since it is much less soluble and is often attached to soil particles.

In 2000, the U.S. EPA *National Water Quality Inventory: 2000 Report to Congress* identified the major causes of impairment in surface water quality for the nation. Although agricultural runoff has been reported to have caused water quality degradation in many cases (48 percent), an additional 34 percent of the impairments to rivers and streams were caused by hydrologic modifications to landscapes, habitats, and urban areas. It is difficult to attribute the exact costs of such pollution to the public and private sectors. However, considering that Congress has allowed for approximately $1 to 3.4 billion/year at the beginning of the establishment of TMDL programs to protect our nation's water bodies, it is clear that the costs to the municipal authorities and stakeholders will be substantial (*2*).

All vegetation requires three major nutrients to sustain growth—nitrogen, phosphorous, and potassium. Nitrogen is used by the plant material to develop healthy leaves for food production, phosphorous to promote flowering activity and seed material, and potassium for healthy root development. Minor nutrients such as calcium, magnesium, and sulfur and trace minerals such as copper and zinc are also required for strong roots and stems. These nutrients can be provided to the soil through synthetic or natural amendments.

Chemical fertilizers are typically classified based on the content of nitrogen (N), phosphorous (P), and potassium as potash (K) as needed energy inputs for vegetative growth. Thus a bag of 10:20:20 fertilizer is comprised of 10 percent nitrogen, 20 percent phosphorous, and 20 percent potassium as potash. Potash is an old term for potassium salts. Potash, which was originally mined, was usually found as potassium carbonate (K_2CO_3), but cheaper salts are now usually used in fertilizers, such as potassium chloride (KCl) and potassium oxide (K_2O).

A switch from chemical-based (manufactured) amendments to more natural or non-chemical amendments has important advantages for runoff and pollution mitigation. In order for the watersheds to meet the restoration criteria, every potential non-point pollution source including agricultural, industrial, municipal, and state activities will be required to implement best management practices and innovative approaches to improve water quality. As a major developer and potential non-point source through project construction and landscape development activities, all departments of transportation including the Texas Department of Transportation are expected to manage operations to comply with TMDL programs and best management practices.

CHEMICAL OR PREPARED FERTILIZERS AND AMENDMENTS

Chemical or synthetic fertilizers are prepared from mixtures of inorganic salts, which can be rapidly dissolved in water to provide doses of nutrients to vegetation. The chemicals are often called quick release fertilizers because of their high solubility and rapid dissipation after watering. The compounds are absorbed quickly by the plant root systems, and the compounds can be looked at as providing bursts of energy to the plant, stimulating growth. However, the chemicals are not designed to provide nutritional value such as a carbon source for cell growth or trace minerals for long-term health.

Energy inputs into chemical and prepared fertilizers and soil amendments versus non-chemical amendments include additional production costs, labor, and monitoring to adhere to the safety requirements for application, additional watering to solubilize all of the material and the potential of repeat applications due to surface application removal after storm events.

While chemical fertilizers can be helpful in small quantities, misuse and overuse of fertilizers is often likely to occur in agricultural and landscaping applications since soil tests (which can identify specific soil nutritional deficiencies) are not often available or statistically significant for large areas. Soil tests can be time consuming (they are usually sent to external labs), and for large areas collecting representative samples over large distances and varying depths may not be practical. Thus chemical fertilizers may be over-applied to save time and to ensure the plant receives a maximum level of nutrients. This has potential for creating a dangerous situation for runoff to streams and water bodies. TxDOT professionals are well aware of the potential to "burn" or kill plant material with excessive nitrogen applications, and in some cases, plantings are often under-fertilized, which can also inhibit a successful project *(3)*.

When the entire life cycle of chemical fertilizers is considered, even more risk to the environment will occur during fertilizer production operations, fertilizer storage operations, loading and transport, and regional storage and distribution. Even with the greatest of care, in each instance spillage and waste material can be created to some degree *(4)*.

Insecticides and pesticides, including herbicides such as glyphosate and pesticides such as chlorpyrifos, can be useful tools and are often applied for various reasons to the roadside landscapes. The applications of these products, however, have controversial environmental effects, often require repeat applications, and are energy intensive such that their use should be minimized as much as possible in a sustainable landscape.

NON-CHEMICAL OR NATURALLY DERIVED SOIL AMENDMENTS

Non-chemical material with more naturally-based substances can help minimize long-term costs by enhancing the landscape's sustainability. The application of chemical amendments is often less expensive than the naturally derived products; however, the chemical products often require multiple re-applications over the life of the plants and do not have the advantages of organic material which can supply carbon and micronutrients.

Nutrient Availability

Phosphorous in organic amendments can be supplied through the application of small amounts of materials such as bone meal or fish meal. Too much extractable P can be leached out and cause algal blooms in receiving waters, although excess P is not toxic to plants in most applications.

The University of California at Davis (UC Davis) Soils and Revegetation Laboratory was contracted by the California Department of Transportation (CalTrans) in 2002 to investigate treatments for barren road shoulders and rights-of-way for plant growth limiting conditions, and to develop more effective treatments to re-establish vegetation on barren, erosive sites. The UC Davis group recommends the provision of 35 pounds of N/acre (20 kg N/ha) if some low amount of residual soil material exists, or up to 120 pounds of N/acre (70 kg N/ha) if the site is drastically disturbed, but rapid plant growth can occur to take up any excess N *(5)*.

As far as release of nutrients is concerned, fungal byproduct type soil amendments release about half of the contained nutrients in the first year and lesser amounts in subsequent years *(6)*. Some urban areas may receive as much as 30 pounds of N/acre/year (14 kg N/acre/year) adjacent to major highways through atmospheric deposition, in contrast to rural areas which can receive only 1 to 4 kg N/acre/year according to the UC Davis study. For disturbed soils, and any amendments added, an estimate of 1 to 2 percent of the total N can be assumed to be mineralized each year to be available for plant growth. Other studies from many locations appear to indicate that 1000 to 1500 kg total N/ha to 30 cm depth is a reasonable threshold for growing sustainable vegetation on disturbed sites (5).

pH

These amendments should also be applied without upsetting the balance of pH and soluble salts. Soil pH is preferably neutral in the range of 5 to 8 for optimal rhizosphere bacterial and plant cell metabolics. Typical amendments for changing soil pH are lime and sulfur. Lime is usually in the form of calcitic limestone (calcium carbonate) or dolomite, which is a finely ground calcium magnesium limestone. Lime is used to stabilize the soil during highway construction and is often present in the soil that is used for landscape development adjacent to the roadway. However, in parts of Texas, alkaline soils are common, and some native vegetation has been known to grow in highly alkaline soils. East Texas typically has a more acidic pH. Some South Texas native plants have been able to grow in red mud beds made of bauxite tailings at pH 9 near the Sherwin Alumina Plant in Gregory, Texas. Alkaline soil pH can be lowered and compacted soil softened by the addition of elemental sulfur, which gradually oxidizes to sulfate ions, thereby lowering pH. Gypsum, which can also be used to soften compacted soils, does not lower pH because the calcium ion and sulfate ions counteract to maintain pH levels.

Cation Exchange Capacity

The cation exchange capacity (CEC) is a value used in a soil analysis to indicate the soil's ability or capacity to hold cation nutrients and is determined by the amount of clay and/or humus present in the soil. Soils with little organic matter or sandy soils have a low CEC (7). The CEC values for healthy amended soils should not be significantly less than about 10 cmol/kg of soil. This capacity to retain cations includes the retention of needed nutrients such as potassium, calcium, and other micronutrients to keep them from leaching out during rainfall events. Organic amendments such as humic substances in compost have relatively high CEC values and are usually negatively charged, which can retain the needed positively charged cations. Other mineral additives such as zeolites, an alumino-silicate clay mineral with a rigid crystalline structure, have a high CEC and also retain nutrients and moisture.

Mulch

Mulch is a term typically used to describe large particles of woody material that has been chipped or shredded. At least 25 to 33 percent of the woody materials are polymers of lignin, which after cellulose and chitin is one of the most abundant organic compounds on earth. Mulch is important to conserve moisture, providing shade and underlying porosity for moisture retention in landscape development projects.

Compost

Compost is a primary material classified as a non-chemical soil amendment that is comprised of natural slightly biodegradable materials, which can improve soil quality. The primary active component of composted materials are humic substances, which comprise the majority of what is sometimes called natural organic matter, the refractory carbon based material derived from plant and residue materials after undergoing a process known in nature as humification. Compost differs from mulch in that it requires time to thermophylically process the feedstock (biosolids, animal manures, and green wastes) and render compost.

In the composting process, organic materials and wastes are blended with a bulking agent (typically wood chips) to create a stable mixture that is provided moisture and aerobic (oxygen supplied) conditions that stimulate biodegrading bacteria and fungi. The organic matter in the blend is used as the carbon and energy source for the microorganisms and is transformed over time into a refractory or stable product. The composting process optimally reaches temperatures of up to 150°F along with moisture content between 50 to 60 percent to eliminate pathogens. Over time the compost pile temperature drops to below 105°F, and a period of between 2 to 6 months for maturation of the stability is required *(6)*.

A major benefit of composted or organic amendments is the slow release character of the nutrient content. Smith and Hadley *(8)* determined that the nitrogen release character of organic amendments more closely matched the timing of the nutrient needs for some plants than synthetic fertilizer. A long-term study established in 2001 in Victoria, Australia, discovered that compost was a rich source of slow release nutrients and adsorbed up to 10 times its weight in water during irrigation *(9)*. Phosphorous availability has also been reported to be increased with the addition of compost materials (*10*). In agriculture applications, healthy crops can be grown in soils with organic amendments to a level superior to that of applied synthetic fertilizers (*11*). Naturally based fertilizer material can be blends of natural organic and inorganic materials such as blood or bone meal, feather meal, green sand, or manure. Compost or biologically manufactured organic matter is more weakly concentrated with nutrients, and its ingredients are only sparingly soluble in water, which creates slow release of materials. It may take days or weeks before nutrients from some of these amendments are made available to the plant roots.

However, compost also provides improved soil structure, aeration, and improved moisture retention, which chemical amendments cannot. Without the carbon sources from the organic matter in compost, healthy biotic cells cannot be created no matter how much chemical fertilizer is applied. Research done by Kirchhoff, et al, showed that the application of compost can reduce erosion, reduce runoff, and reduce the need for chemical fertilizers and herbicides when applied at rates of 0.5 inches to 2 inches and tilled to a depth of 5 inches to 7 inches. However, the potential problem with its use comes from inconsistent compost quality, leaching of nutrients, the accumulation of heavy metals, and salt levels during initial application (*12*).

Compost can be a high source of K (up to 5 percent). Calcium can be applied in compost, gypsum, or lime. Magnesium is commonly not limiting and rarely monitored closely. Excessive application of Ca can increase the pressure of some plant communities by annual weeds. Other essential micronutrients typically provided through composted material amendments include zinc, manganese, iron, and copper. High levels of boron and molybdenum can be toxic and are not often found in excessive amounts in properly composted materials. Yard waste and wood waste composted materials can provide these micronutrients.

Humic Materials

Natural organic-based soil amendments can enrich the soil, provide critical components, and also assist in pollution mitigation. The largest fraction of the most stable organic material in composts can be classified as humic material (humates) or natural organic matter. Humic substances are classified into two major components, namely humic acid (HA) and fulvic acid (FA), on the basis of their solubility in acids and bases. HAs are those substances that are insoluble under acidic conditions (at pH < 2) but soluble at high pH values. FAs are soluble at all pH values and are generally characterized by low molecular weight but high oxygen containing organic components.

OTHER AMENDMENTS

There are numerous organic amendments available for use and most can be found in Appendices B, C, and E. Most of these amendments are byproducts from other industries such as residuals from agriculture, food processing, animal processing, and mineral derivatives. The most commonly found organic and mineral amendments are listed below.

Alfalfa Meal and Pellets	Blood Meal	Bone meal
Calcium Carbonate	Corn Glutten/Meal	Cottonseed Meal
Dolomite	Epsom Salts	Feather meal
Fish Meal/Emulsions	Granite Meal/Dust	Greensand/Glauconite
Gypsum	Guano	Humate
Kelp/Cytokinin	Langbeinite/Sulfate of Potash Magnesia	
Lava Sand	Molasses	Rock Phosphate/Calphos
Soybean Meal	Sphagnum peat Moss	Sulfur
Worm Castings	Zeolites	

The major markets for these products are residential and commercial landscape development. Howard Garrett, a horticultural expert from Dallas, Texas, has determined that while many nutrients from the naturally derived materials are "slow release," they also provide enough levels for a quick start and strong vegetation establishment, especially green sand and dry molasses (*13*). Some products are manufactured, packaged and distributed for agricultural uses in organic food production. The agricultural sources are the most promising for use on the roadside because they are available in the quantities and use application techniques that relate to the large scale of projects constructed on the roadsides. Generally, these amendments have a lower nutrient value than commercially produced chemical fertilizers and often have a slower nutrient release time. However, the beneficial use of organics far outweighs inorganic fertilizers and amendments in their ability to rehabilitate the soil as discussed in previous chapters.

MICROBIAL STIMULANTS AND INNOCULATION

Even in the case of highly disturbed roadside soils, some indigenous mycorrhizal fungi and bacteria are probably present. Some microorganisms will inevitably be present in very low amounts within the organic amendments themselves. Thus, in the restoration of these soils, the addition of bacterial inocula is not a recommended practice. The indigenous species, with sufficient nutrients, moisture, and aeration, can be developed in situ along with the vegetation root establishment for a more sustainable landscape. However, some researchers have suggested that the inoculation of endomycorrhizal fungi, which are often present in natural forest soils and serve to increase the transfer rate of nutrients and moisture in the plant root zone, should be considered in the restoration of some disturbed soils (*5*). The microbial populations of disturbed and revegetated sites have not been extensively studied.

TxDOT's Lubbock District implemented a roadside demonstration project to test the ability of different root-zone treatments to enhance tree growth and performance. The district used three different root zone treatments for a 65-acre site with over 1200 trees. This semi-arid region was looking for something that would enhance water retention and promote growth. At the time of planting, a 5-gallon drench with 5-ounce treatments per 100 gallons of water was applied at the root zone. This drench was repeated every 30 days for 90 days (four applications). The dry materials were incorporated into the backfill materials and applied at the time of planting only.

- Treatment 1
  - Dry soluble yucca plant extract (Yucca schidigera) as surfactant
- Treatment 2
  - Dry soluble yucca plant extract
  - A minimum of 1000 spores of Vesicular-Arbuscular (VA) fungi to include Entrophosopora columbiana, Glomus etunicatum, Glomus clarum, and Glomus sp. per 1-inch caliper of tree
- Treatment 3
  - Dry soluble yucca plant extract

- A minimum of 1000 spores of Vesicular-Arbuscular fungi to include Entrophosopora columbiana, Glomus etunicatum, Glomus clarum, and Glomus sp. per 1-inch caliper of tree
- Super-absorbent acrylamide copolymer, soluble sea kelp extract (Ascophyllum nodosum), and humic acid (Leonardite humates)

The majority of the trees receiving Treatment 3 had greater growth response compared to the other groups. However, the treatment types are species specific in their overall effectiveness (*14*). Since this was an in situ project, issues such as tree maintenance, i.e. trimming and replacement, became paramount with regard to data collection and consistency of results due to lack of communication between maintenance personnel and those tracking the tree growth data.

Organic amendments are also used as soil microbial stimulants. Many of these are derived from composted materials such as guano, typically bat guano, and earthworm castings. Food sources for soil microbes include molasses, dried alfalfa meal and pellets, corn meal and gluten, humates, and lava sand. An active soil microbe community aids in the decomposition of organic matter, such as leaves and debris, and utilization of available nutrients from this process in the soil (see Appendices B and E).

LIQUID ORGANIC AMENDMENTS

The sparingly soluble acids found in the humic and fulvic acids are also expected to be a large component of what is often referred to as "compost tea." As applied water percolates to the root zones, these slightly soluble humics are transported but at a very slow rate due to the neutral pH, which inhibits humic and fulvic acid dissolution. Ultimately the elemental composition of most humic material falls into several ranges based on source material and process conditions, but carbon contents of 45 to 55 percent are typical, and nitrogen contents are variable from 0.1 to 5 percent.

The compost tea product is produced by leaching the soluble material from the composted material using a water solution that is sometimes amended with molasses or fish powders. The brewing process for many products has been completed with various methods, which can create uncertainties in the final product quality.

The different methodologies of preparation/application for these liquid amendments can create confusion in the implementation of a successful project. Good quality compost should make high-quality compost tea. There are a variety of methodologies/techniques under which recipes are generated (*15*). In many cases it depends on the ultimate purpose. For example, ingredients in one recipe might change in another if more nutrients were needed in a particular area. The occurrence of such a vast variety of methodologies is caused by local efforts to improve nutrient efficiency and decrease the cost of the process. Performance of the compost tea can depend on several key factors such as the initial compost quality, the preparation, and the application methods. It is also essential that the compost used prior to brewing have soluble nutrients and microbial populations (*15*). This variability in the brewing process can make this product uncertain in quality and effectiveness for large landscape development projects; however, the ability to foliar feed large areas with standard roadside maintenance equipment may provide a viable application alternative.

SOIL AMENDMENTS AND DE-COMPACTION

Soils make a transformation from undisturbed to highly disturbed during the highway construction process. Other than the removal of organic horizons from the area designated for landscape development, soil compaction plays a key role in the vegetation's ability to uptake nutrients, air, and water. Table 3.1 lists the key parameters of concern as soil is transformed from an undisturbed soil to a post-construction soil.

Table 3.1. Transformation of Soil Characteristics from Undisturbed to Disturbed (2,3).

Comparative Soil Physical, Chemical and Biological Properties		
Undisturbed Soil	→	**Post-Construction Soil**
40 – 55%	Compaction ↑	95 – 98%
1.1 – 1.4 g/cc	Bulk Density ↑	1.5 – 2.0 g/cc
	Aggregate Stability ↓	Decreases
	Porosity ↓	Reduced
Adequate	Organic Matter ↓	Reduced or absent
Present and active	Micro-organisms ↓	Reduced
35%	Storm water Infiltration ↓	15%
15%	Storm water Runoff ↑	55 – 70%
	Water-holding Capacity ↓	Reduced
	Available Water ↓	Reduced
Yes	Available Nutrients ↓	Very reduced
	pH	Altered
	Electrical conductivity ↓	Reduced
	CEC ↓	Reduced
	Rooting Penetration	Resistant

In addition to these characteristics, Texas soils can present significant challenges for landscape development even in its undisturbed state, and are often described as "hard pan" in West Texas, attributed to the dry cohesive soils with narrow particle size distributions, and "gumbo" or heavily clay laden in areas of North Texas. This is even prior to the compaction caused by the mechanical disturbance of the equipment during highway construction.

The University of California at Davis Soils and Revegetation Laboratory was contracted by the CalTrans in 2002 to investigate treatments for barren road shoulders and rights-of-way for plant growth limiting conditions, and to develop more effective treatments to re-establish vegetation on barren, erosive sites.

According to Claassen at the UC Davis Soils and Revegetation Laboratory (5), several key parameters were found to be critical to successful vegetation establishment when starting with barren soils. The slope must be geotechnically stable, and the design of the site must provide for adequate rooting depth for the plant material selected. Additionally, the amount of soil organic matter present must provide for three important functions including infiltration, microbial activity, and nitrogen for plant growth through organic matter degradation (5). They recommend a rooting depth of 3 feet for trees and shrubs and state that compacted fill materials on slopes are often not adequate for rooting for large plants. However, TxDOT has successfully established roadside planting in lesser conditions. Cut benches and additional loose fill can be strategically placed to provide a stable slope and also some opportunity for larger root growth. The infiltration of applied moisture is also critical because many Texas soils high in clay and fine particles can create crusts that can impede vegetation establishment. Water holding capacity can be improved with organic amendments, but some limitations can occur with very fine soil particle sizes, such as less improvement in water holding capacity. The water holding capacity for sandy, coarse soils has the potential for larger increases with the addition of these organic materials.

For surface tillage the UC Davis investigators also recommended that unscreened compost material be added to a depth of 2 inches (50 mm) and tilled to 12 inches (300 mm) using an incorporating ripper shank. TxDOT's Houston district applies a similar tillage technique to its urban roadside landscapes by specifying that planting beds receive a rip/trench depth of 18 inches with 24 inches between each rip/trench and rotor tilling in of amendment application to 8-inch depth.

This application of compost can easily provide about 10 to 20 pounds N/acre, which is reasonable for a highly nutrient and organic matter depleted, disturbed soil—roughly equivalent to 650 cubic yards or 500 m^3 of material *(5)*. To achieve effective infiltration in soils that have some nutrients but that are over-compacted, an amendment with coarse wood chips from screening woody and yard waste compost through a ½-inch screen can be used to improve soil porosity and permeability with less nutrient amendment.

Soils can be aerated and de-compacted using a variety of plant and mineral derived products. As stated in Chapter 2, the addition of organic matter to the soil will help alleviate soil compaction. The most commonly used additives, other than compost, are as follows. An expanded list can be found in Appendix B.

- Greensand or glauconite consisting of dried ocean deposits, usually contains 5 to 7 percent potassium, trace mineral and silica;
- Gypsum or calcium sulfate powder usually contains 22 percent calcium and 17 percent sulfur;
- Lava sand, a waste material from lava gravel;
- Humate, humus, humic acid, and fulvic acids, derived from lignite coal and clay;
- Sphagnum Peat, harvested from peat bogs;
- Earthworm castings; and
- Mycorhiza inoculation using beneficial fungi.

WEED CONTROL

Some organic amendments may be effective as herbicides. Corn gluten, for example, has been observed to reduce weed germination and yet provide nitrogen to established plants (*16*). Although there is controversy over verifiable research regarding corn gluten's effectiveness as a pre-emergent weed killer, there is much anecdotal testimony to its effectiveness.

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CHAPTER 4: POLLUTION PREVENTION AND MITIGATION THROUGH LANDSCAPE PRACTICES

This chapter describes different methods of pollution mitigation and prevention through sustainable landscape development approaches that can be applied to the roadside landscape. The breakdown and transport of organic materials and their release of nutrients are also described and compared to synthetic chemical treatments. The behavior of these natural materials, not surprisingly, can serve to reduce runoff and pollutant transport because of their structure, composition, and biodegradation rates.

POLLUTANT REMOVAL

Sustainable landscapes have a great potential to mitigate runoff, and air pollution. For example, the establishment of sustainable vegetation in a buffer strip between receiving water and an adjacent agricultural area has been known to be an effective mitigation technique for runoff pollution. The retention capabilities of the vegetation prevent many agricultural chemicals from polluting receiving water bodies. A study of an agricultural watershed and riparian forest in Maryland (*1*, *2*) found that if the riparian forest were removed, the nitrate nitrogen loading to the nearby stream would have been doubled over time. These vegetated zones also increase infiltration, allowing swifter groundwater recharge and natural filtration for water supplies and less runoff.

Constructed wetlands and storm water retention areas can also improve water quality. Case studies of these water quality improvements have been reported to remove up to 96 percent of biochemical oxygen demand (BOD_5) and up to 94 percent of total suspended solids (*3*). Wetlands are especially effective in removing nutrients such as phosphorous along with the suspended solids from polluted runoff (*4*). Wetlands vegetation, designed as storm water detention wetlands to handle intermittent flows, can significantly improve water quality (*5*). One analysis proved that the Congaree Bottomland Hardwood Swamp wetlands in South Carolina can provide valuable water quality functions such as sediment, toxicant, and excess nutrient removal equivalent to building a water treatment plant costing $5 million (*6*).

Successful landscapes with trees can take up airborne pollutants through stomata and produce more oxygen in urban settings. Ozone, sulfur dioxide, carbon monoxide, and other particles can be removed from air with the vegetation (*7*). A large landscape in the city of Chicago with 11 percent coverage of trees was estimated to remove 17 tons of carbon monoxide, 93 tons of sulfur dioxide, 98 tons of nitrogen dioxide, and 210 tons of ozone in one study (*8*). The value of this pollution removal was estimated at $1 million annually. In Tucson, Arizona, a similar study determined the annual value of this pollution control measure at about $1.5 million annually for another group of landscapes (*9*). Reductions in particulate concentration of 19 percent were recorded near Ohio conifer stands (*10*).

Additional evidence has been accumulated indicating that compost materials used in applications for storm water control also have the benefit of improving water quality by retaining nutrients and pollutants from roadway runoff. Figure 4.1 shows a low cost but effective storm water retention application made of composted materials with the potential to retain suspended solids and nutrients. Figure 4.2 depicts an example TxDOT application site of mulch and compost amended soil material in the Houston area. This application also has the potential to reduce nutrients in storm water runoff and retain moisture, utilizing the mechanisms outlined in this chapter.

Low impact development engineering projects incorporating these materials, such as retention and treatment swales, infiltration galleries, and storm water retention ponds, can be very cost-effective methods to improve and protect regional water quality. In many cases, humic materials have been known to reduce the toxicity of legacy pollutants and toxic chemicals in the aqueous phase in runoff and storm water (*11*). Other studies have demonstrated the strong binding capacity of humic substances for metal ions. Thus positively charged cations such as lead, copper, and iron are easily attached to the negatively charged carboxyl functional groups commonly found in the naturally derived humic materials.

Figure 4.1. Filter Sock Packed with Composted Material Applied for Storm Water Pollution Control (Provided by TCEQ).

Figure 4.2. TxDOT Compost and Mulch Application (Houston District).

LOW IMPACT DEVELOPMENT CONCEPTS

Low impact development (LID) is an approach to site design that has the goal of minimizing, detaining, and retaining post-development runoff to replicate pre-development hydrologic functions (*12*). This can be accomplished by restoring or improving the hydrologic characteristic of the soil by amending the soil's physical characteristics. According to the Low Impact Development Center, "Compared to compacted, un-amended soils, amended soils provide greater infiltration and subsurface storage and thereby help to reduce a site's overall runoff volume, helping to maintain the pre-development peak discharge rate and timing" (*13*). According to Larry Coffman, an expert on LID technology for water resources and ecosystem protection and restoration, LID has potentially less environmental impacts through the use of design and technology tools that achieve a better balance between conservation, growth, ecosystem protection, public health, and quality of life (*12*).

Integrated LID Programs

Fairfax County, Virginia, is implementing an approach to low impact development with the compilation of draft best management practice (BMP) fact sheets that present an overview of LID management strategies and technologies. Fairfax County's LID BMP Fact Sheets include seven functional categories. Those with potential relevance to TxDOT roadsides are:

- Bioretention systems:
    - bioretention basins
    - bioretention cells
    - bioslopes
    - bioswale
    - tree box filters
- Filtering technologies:
    - catch basin controls (proprietary and non-proprietary)
    - dry wells
    - water quality swale/grassed swale
- Permeable pavements:
    - infiltration trench

    - permeable/porous pavements (asphalt, concrete, pavers)
- Site design strategies:
    - disconnect impervious areas/downspout disconnection
    - flow splitters
    - time of concentration practices/surface roughening
- Soil amendments
- Vegetative systems:
    - reforestation/afforestation
    - bayscaping and environmentally sensitive landscaping
- Water conservation/reuse:
    - cisterns/rain barrels
    - pollution prevention *(14)*.

This approach is easily implemented when building a subdivision or commercial development. Some of these techniques will translate to the roadside and can be implemented to accomplish sustainable landscape goals. One LID technique that needs further investigation by TxDOT is the bioretention facility.

Bioretention

One methodology for integrating water quality improvement into the roadside environment may lie in designing multifunctional, sustainable roadside landscapes. Storm water management is an integral part of TxDOT's design process. Some urban roadside landscapes may have potential for design or re-design to perform the functions of storm water detention, retention, filtration, or runoff control. A bioretention cell is similar to an infiltration gallery designed to collect runoff and allow it to percolate gradually through a media of soil, sand or woody material which contains a healthy microbial consortium targeting removal of nutrients and pollutants. The current practices used in the Houston District closely replicate a bioretention cell used for storm water quality treatment, as shown in Figure 4.3.

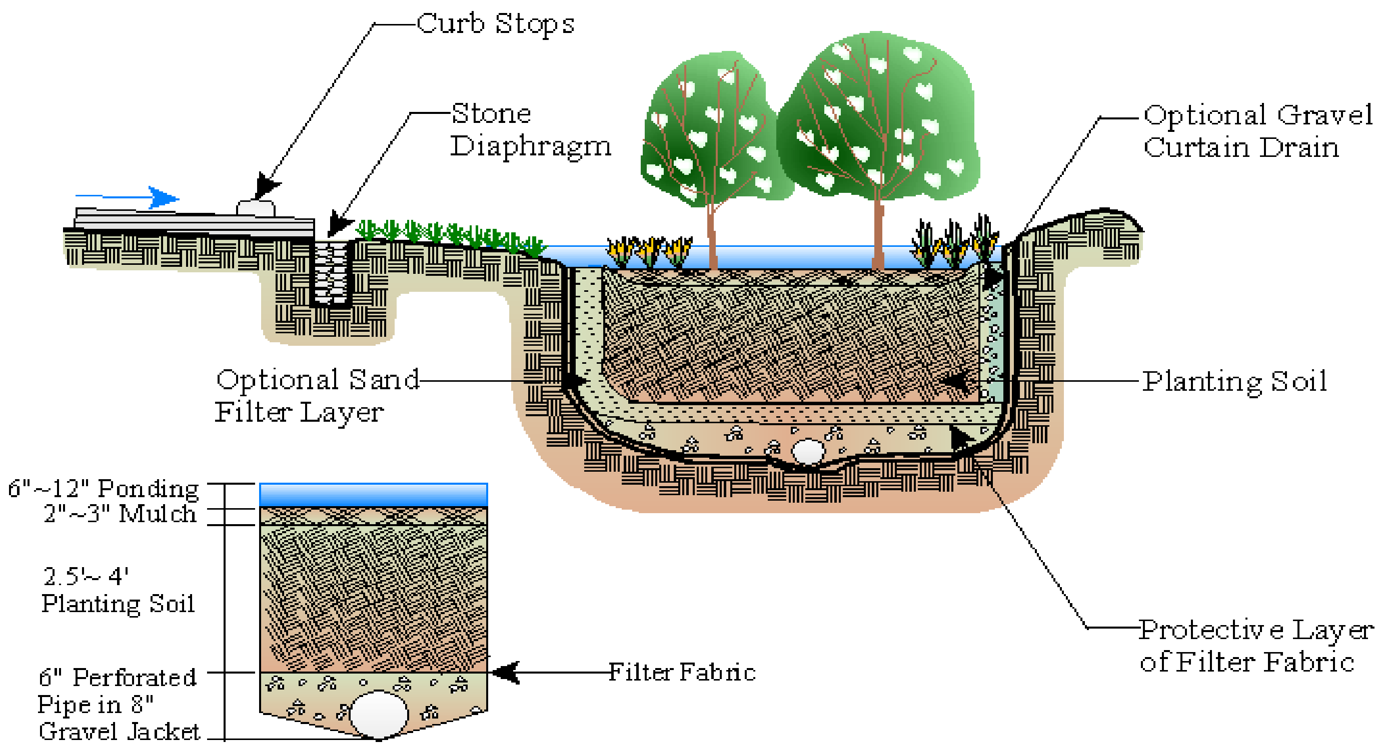

Figure 4.3. Bioretention Cell (*15*).

The Houston District has implemented an approach similar to bioretention in its large-scale planting area under their reforestation projects. The Houston District's specifications for their reforestation projects include mass planting of trees with an under-story and canopy to simulate a natural environment. See Appendix F for planting establishment plan sheets. The planting beds preparation is as follows (however, there may be project specific alterations):

- General use compost (Item 160-2012)
  - 2-inch uniform layer
- Landscape soil amendment (Type I)
  - 60 pounds/200 square yard (SY)
  - Non-chemical fertilizer
    - Registered with Texas State Chemist as a commercial fertilizer
    - Meets EPA guidelines for unrestricted use
    - Derived from biological sources such as, but not limited to, sewage sludge, manures, vegetation, etc.

- Landscape soil amendment (Type II)
    - For plant bed applications
        - Type I, Type II, and Type III—25 pounds/200SY
        - Type IV—50 pounds/200SY
    - Humate containing 1.5 percent sulfur and 2.25 percent iron in raw material and greater than 45 percent humic acid, dextrose 2.5 percent to 5 percent on weight basis
- Landscape soil amendment (Type III)
    - 20 pounds/200SY
    - Granular/pelletized and naturally derived sulfur
- Ripping/trenching
    - Rip/trench depth 18 inches with 24 inches between each rip/trench
- Rotor tilling
    - After amendment application rotor till to 8-inch depth

In specific urban locations, a modified planting bed/cell could prove to have a similar water quality effect as a bioretention process. In a bioretention cell, tree canopies intercept rainfall and provide a major source for evapotranspiration. The 6- to 12-inch ponding area provides detention of runoff. The layer of organic litter/mulch provides pollutant removal and water storage. The planting bed soil provides infiltration of runoff, removal of pollutants through numerous biological and volatilization processes, groundwater recharge, and evapotranspiration through the plant material *(16)*.

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CHAPTER 5: LARGE-SCALE PUBLIC AND PRIVATE LANDSCAPES: THE PARADIGM SHIFT TO SUSTAINABLE LANDSCAPE MANAGEMENT

STATE DEPARTMENTS OF TRANSPORTATION

Many state transportation agencies recognize the need to reduce the energy input into their roadside landscapes. With this, many agencies have implemented policies and procedures for roadside landscape development that incorporate methods and technologies of sustainability.

New York State Department of Transportation

The New York State Department of Transportation (NYSDOT) is implementing design techniques to fulfill the goals of their *Environmental Policy* of 2000 (*1*). Relevant to sustainable roadsides, these goals include:

- protect and improve water and air quality,
- reduce the use of non-renewable energy resources,
- reuse and recycle materials,
- reduce or eliminate hazardous substance use,
- clean up transportation-related contamination where appropriate,
- promote quality communities and sustainable development,
- enhance the visual, aesthetic and natural character of roadsides or streetscapes, and
- advance Context Sensitive Design (*1*).

Massachusetts Highway Department

The Massachusetts Highway Department has guidelines for naturalized landscape development in their January 2006 document for landscape aesthetics (*2*). In Section 13.3.2, "Natural Site Landscape Treatments," the document describes natural sites as follows:

> Natural sites, as distinct from streetscapes, are those locations (urban and rural) where the principal objectives and concerns involve natural systems. Landscape design for natural

sites encompasses surface stabilization of cuts and fills; containment and filtration of storm water runoff; tree replacement and reforestation; buffering of roadside ecosystems and habitats; screening views to and from the road; mitigating wind and snow drift; and habitat enhancement. In general, design for natural sites is primarily comprised of appropriately selecting and placing plant material.

Florida Department of Transportation

The Florida Department of Transportation (FL DOT) also sees the benefit of designing roadside landscape with energy conservation in mind. Water as a resource for maintaining roadside landscape development is an important and sometime controversial issue in many states, including parts of Texas where water is a precious commodity. FL DOT has adopted many conservation techniques in their *Florida Highway Landscape Guide* (*3*). This includes the following xeriscape principles and guidelines:

- Appropriate choice of drought tolerant native and adapted plant materials for the site,
- Improve the soil as necessary,
- Efficient irrigation,
- Practical use of turf grasses,
- Appropriate use of mulches, and
- Proper maintenance (3).

Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) defines a sustainable roadside as "those roadsides that are designed and maintained with the intent of integrating successful operational, environmental, and visual functions with low life cycle costs" (*4*). They have a system in place through their *Roadside Manual,* "Chapter 120—Sustainable Roadsides" (*4*). This details many aspects of roadway construction including soil amendments.

The recommended soil amendments are topsoil, compost, bark or wood chip mulch, fertilizer, and mycorrhiza. To encourage native woody plant growth, WSDOT recommends incorporating 3 inches of compost into the top 12 inches of soil and then placing a 3-inch layer of bark or wood chip mulch on the soil's surface. WSDOT procedure includes leaving organic matter on the ground as long as it does not pose a safety threat. This enriches the soil, reduces the need for additional fertilizer, and provides habitat. All of these are designed to reduce maintenance costs (*4*).

Texas Department of Transportation

The TxDOT Landscape and Aesthetic Design Manual (5) outlines specifics about landscape restoration, habitat creation, and naturalization. Safety, sustainability, and life cycle costs are key design factors for any project. For many urban areas, naturalization is the best approach. As defined in the manual, naturalized areas are where the plant communities are preserved or established either as an aesthetic program or as part of habitat creation: "Naturalization seeks to promote or re-introduce native plants to minimize maintenance or improve the aesthetics of the roadside. This will usually involve the seeding or planting of desirable plants and periodic management to assist in their survival or it may focus on preserving threatened or endangered species" (5).

The rationale behind naturalization of the right-of-way is to remove large areas from routine maintenance activities, thereby reducing the monetary and energy output for that location. Often these are located in large interchanges; however, this type of sustainable system can be implemented in confined spaces also, as shown in Figure 5.1. According to TxDOT, "In these projects, plant material that would not normally be appropriate for use in other roadside applications may be desirable as a part of urban reforesting programs, wildlife habitat, or storm water quality programs" (5).

Figure 5.1. Houston District's Naturalized Ultra-urban Landscapes.

Several TxDOT districts have implemented the naturalized or sustainable landscape design approach. Pat Haigh, landscape architect for the Dallas District, recommends using plant materials that are native or naturalized/adaptive for the region, placing them in "plant communities" and proper planting bed preparation. These plant communities mimic natural conditions by providing a tree canopy of variable widths, edges with mixed under-story plants, and a transition to grasses/clear zone cover as shown in Figure 5.2. The Houston District has a program in place for native naturalized "reforestation" of the roadsides using intensive plantings and the addition of organic matter to amend the soils. The emphasis in this district is to start with the soil since it provides the plant with the ability to grow and sustain. Much of these efforts have been prompted by legislation, old and new. The new federal transportation bill, Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) refers to the high priority project No. 825, implementation and quantification of benefits of large-scale landscape along freeways and interchanges in the Houston region.

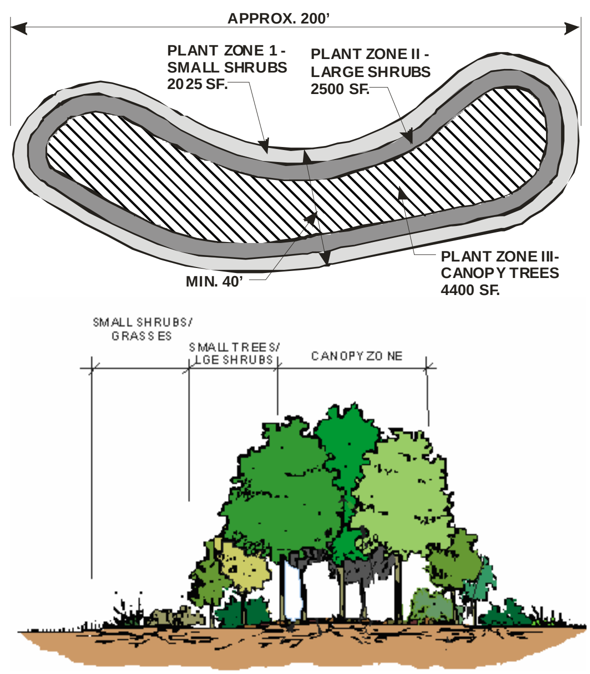

Figure 5.2. Naturalized Landscape (5).

The most important aspect of the bed preparation is soil improvement with the addition of organic materials. This loosens the soil and creates a favorable microclimate for the plant root zone. The use of mulches is effective in reducing weeds, regulating temperature, and increasing water retention.

The Houston District has successfully implemented this program and has several standard sheets that are part of the design and construction documents (see Appendix F). Houston District's Green Ribbon Program is a response to the local legislative and public demand to incorporate a higher level of aesthetics and landscape development into the state's roadway facilities. They have received several awards for their efforts with establishing naturalized roadsides that incorporate sustainable landscape methods.

THE CORPORATE/CAMPUS LANDSCAPE

Many corporate and college campuses are shifting to more energy efficient building and landscape policies, programs, and technologies. Green or sustainable building practices, low impact development, and Smart Growth are all techniques for mitigating the impact of urban development on the surrounding natural environment.

Environmental Protection Agency Programs

The EPA promotes the concepts of naturalized landscapes as part of energy efficient practices. The EPA Region 5 for the Great Lakes area has a Green Acres Program, which has a guideline document, *A Source Book on Natural Landscaping for Public Officials* (6). This document was prepared by the Northeastern Illinois Planning Commission to assist local officials, land owners, and citizens in their efforts to construct or convert large- and small-scale landscapes to naturalized areas. The EPA also has a partnership program called the GreenScapes Alliance that is designed to promote energy efficient public and private landscapes. The EPA recognizes that large-scale landscapes have a unique opportunity to showcase these efforts. These large-scale landscapes are encouraged to "reduce, reuse, recycle, and rebuy" to protect and preserve natural resources. According to the EPA, a GreenScape should use the following practices:

- incorporate renewable biobased products, such as biological, agricultural (plant, animal, or marine), or forestry materials;
- use environmentally preferable products that have a lesser or reduced impact on the environment as compared to similar products or services; and

- use recycled products (*7*).

The GreenScape Alliance is in place to help "combine government and industry into a powerful, unified influence over the reduction, reuse, and recycling of waste materials in large land use applications" (*7*). Relevant to TxDOT, these land use activities include roadside landscaping. Other sites include Brownfields land revitalization, and the beautification and maintenance of office complexes, golf courses, and parks (*7*).

One of the large-scale projects implemented through this programs is the Century Park retail complex in central Oregon (Figure 5.3). Through the use of native and adapted plant materials and an efficient irrigation system that incorporates storm water runoff from parking lots and rooftops, the 33,000-square-foot landscape has reduced energy consumption dramatically. Maintenance costs are 80 to 90 percent below the average traditional landscape of that size. According the EPA, the site is so self-sufficient that it never needs fertilizer, pesticides, extensive watering, or mowing (*8*).

Figure 5.3. GreenScape's Century Park (*8*).

Corporate Lands Natural Landscape Program

There are many private organizations that promote a sustainable or naturalized approach to landscape development. The Openlands Project's Corporatelands natural landscaping program is one of these. Openlands is based in northeastern Illinois and is an independent, nonprofit organization committed to preserving and enhancing public open space. It encourages and supports corporations and large institutions such as colleges and hospitals that are interested in replacing their turf grass landscapes with natural landscapes of plants and grasses native to the Chicago region. This effort is to reduce energy input, pollution, water consumption, and chemical use while promoting wildlife habitat, biodiversity, and water quality (*9*).

State and Municipal Programs

The city of Austin, Texas, is located over the environmentally sensitive region of the Edwards Aquifer. Efforts by the City of Austin include the Green Garden Initiative, WaterWise Landscape Program, and Soil Rebate Program. Each of these provides direction and rebate incentives for the use of landscape practices that conserve water and build a sustainable system through organic soil amendments. The Soil Rebate Program offers incentives to establish a 6-inch soil depth. Soil purchased through the Soil Rebate Program must be amended with at least 25 percent compost (*10*).

Many other municipalities across the country have programs in place that promote sustainable landscapes through water conservation and organic soil amendments. They realize the benefits of landscape practices that promote energy efficiency. The City of Albuquerque has a Rainwater Harvesting Landscape Rebate, which provides incentives for xeriscape landscapes and rainwater harvesting (*11*). The county of Santa Barbara, California, has several energy conservation guides that come under their Green Team: "The Green Team's goal is to increase resource use efficiency and reduce the County's impact on human health and the environment. This goal will be achieved through implementing programs to increase recycling efforts, conserving natural resources, purchasing recycled-content products, and purchasing environmentally friendly cleaning and pest control products" (*12*). The Santa Maria Valley Sustainable Garden is used to showcase their low energy landscape techniques. The City of Redmond, California, has a Conservation and Education Program, which has developed *Guidelines for Landscaping with Compost-Amended Soils* (*13*).

Texas Wildscapes

While conservation and introduction of wildlife to the landscape is primary with the Wildscapes programs, the philosophy remains with a sustainable landscape. According to the Texas Wildscapes information, 82 percent of all Texans live in nine metropolitan areas. Creating wildlife habitat is not generally a goal for TxDOT on highly urban roadsides due to safety; however, the concept of providing a healthy, viable landscape is encouraged. The objectives of the Texas Wildscapes Programs that relate to those of sustainable urban roadside landscapes include:

- provide information on landscaping with native plants;
- improve habitat and environmental quality for wildlife and humanity;
- restore viable wildlife habitat and protect the state's natural resources by utilizing valuable tools to protect water supplies and avoid pressure on landfills;
- promote the use of native plants whenever possible;
- use regional native plants, which have fewer pest problems, require less fertilizer, and (most) thrive with only natural rainfall;
- re-use of grass clippings and leaves, mulching, and composting;
- use water conservation and common sense irrigation;
- minimize the use of pesticides and fertilizers through the use of native plants; and
- implement low-impact pest management (*14*).

Texans spread about five million pounds of fertilizer on yards each year, and due to improper mix and waste, much of it ends up in the state's water supplies. Utilizing compost not only reduces the volume of yard waste that finds its way into landfills, but it also alleviates the need for fertilizer. Compost is a natural, nutrient-rich mulch and soil amendment that can be used in place of fertilizer (*14*).

California Integrated Waste Management Board

The California Integrated Waste Management Board has several programs in place that are designed to change the approach to landscape development. Education is a major component of the program, both on a public and professional level. They emphasize resource efficient landscape practices by encouraging residents and landscape professionals “to reduce green waste, conserve water, and minimize non-point source pollution from urban landscapes” (*15*).

One example of these efforts is the Capitol Park Resource-Efficient Landscaping Project in Sacramento. The landscape was converted to more energy efficient grounds by installing drip irrigation in the shrub beds, mulch, and water-efficient plants. These improvements were designed to help control weeds, conserve water, and reduce water runoff irrigation systems (*15*). According to the Integrated Waste Management Board, sponsor of the Capitol Park Project, a sustainable landscape is “managed by using practices that preserve limited and costly natural resources, reduce waste generation, and help prevent air, water, and soil pollution. “The goal is to minimize environmental impacts and maximize value received from dollars expended” (*15*).

Orange County Landscape Management Outreach is another of these efforts. This program uses outreach activities and events working with local public agencies, waste management organizations, landscape industry associations, and educators. The goals of the outreach campaign are to:

- reduce the volume of green waste disposal in regional landfills,
- increase usage of green materials source reduction and on-site management practices,
- increase usage of recycled organic products in urban landscapes, and
- increase local jurisdictions’ green waste diversion rates to meet mandate requirements (*15*).

Iowa Living Roadways

Iowa has a two-part program called the Iowa Living Roadways, which includes Community Visioning and Project components. The Federal Highway Administration awarded this program the 2003 Environmental Excellence Award. The Community Visioning component encourages creative and strategic thinking about landscape improvements along transportation corridors. The Project component is the implementation of the Visioning plans. Funding is provided through grants for landscape projects that use primarily native trees, grasses, and wildflowers (*16*).

King County Department of Transportation in Seattle, Washington

The King County Department of Transportation in Seattle, Washington, is implementing low energy, naturalized landscapes along its roadways (Figure 5.4). The disturbed roadsides are restored with plants similar to those from the surrounding landscape or plants that are naturalized and do well in the harsh roadside environment. Native trees are mulched on site when removed during construction and used on the planted areas. The goal is to preserve native vegetation where possible and replace or restore the landscaped areas (*17*).

Figure 5.4. King County Naturalized Landscape (*17*).

Seattle Street Edge Project

The Seattle Street Edge (SEA) project also uses several methods to reduce the quantity of storm water runoff. This project incorporates organically amended soils, swales, reduced impervious cover, and abundant plant materials to detain and promote runoff infiltration. Monitoring of the site over a 2-year period showed a 98 percent reduction in the quantity of storm water runoff leaving the site for a 2-year storm event.

The plant materials used were native and salmon-friendly plantings (Figure 5.5). The SEA Street uses grading, soil engineering, plant selection, and layout to function together, similar to a natural ecosystem, utilizing the processes of evapotranspiration and biofiltration to absorb and clean runoff, thereby minimizing the downstream effect of urban pollution from roadways (*18*).

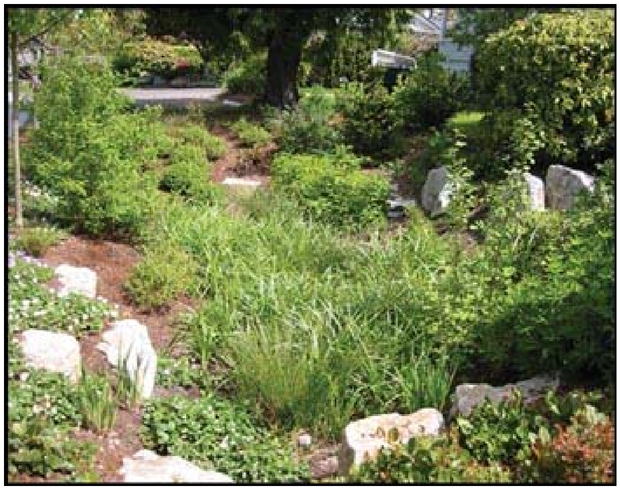

Figure 5.5. Seattle Street Edge Project (*18*).

Soils for Salmon

The Puget Sound in Washington is the most heavily populated portion of the state. Its proximity to the coast and diverse ecological areas makes it a good candidate for projects such as Soils for Salmon. New development in Seattle and surrounding communities increases the quantity of storm water runoff, and this has an impact on the region's environmentally sensitive salmon population. Many entities have come together in an effort to decrease storm water runoff quantities by using organic soil amendment. Public education is an essential component of this program. Graphics, such as those shown in Figure 5.6, help explain the important role of organic matter soil amendments and their effect upon the soil's life. The organically amended soils reduce the impacts of storm water in receiving waters by allowing infiltration and retention of rainfall in post-construction soils. The biofiltration effect of the organically amended soils retains and cleans the storm water, thereby mitigating the adverse effect of urban runoff. The amended soil structure requires less irrigation, requires fewer chemicals, and sustains low energy landscapes (*19*,*20*).

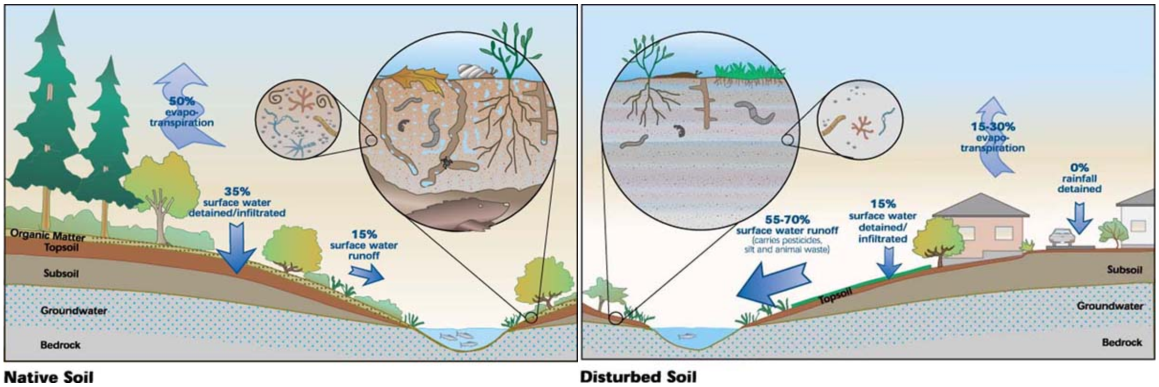

Figure 5.6. Soils for Salmon—Native Soils versus Disturbed Soils (*20*).

Military and Government Facilities and the National Park Service

Governmental agencies that include our national park system, military installations, and government facilities comprise vast quantities of public lands. Land maintained by the Department of Defense on a state and federal level, according to the 1996 publication *Conserving Biodiversity on Military Lands: A Handbook for Natural Resources Managers*, is in excess of 25 million acres (*21*). With the closing of many military facilities, some of this land management has been transferred to other agencies and entities. However, the Department of Defense does recognize that their facilities are large scale and have potential to directly impact the environment. As such, their management approach should be cognitive of and imparted to sustainable development. Leslie et al. (*21*) provide several methodologies, management techniques, and tools for implementation of a more naturalized landscape. Many military bases have implemented these programs and have even applied this approach to their golf course facilities.

The Presidio of San Francisco

The Presidio of San Francisco, California, is now part of the National Park Service (NPS). The 1480-acre site served as a military base or garrison for Spain, Mexico, and the United States for 219 years. The U.S. Army maintained a post at the Presidio for nearly 150 years. When the Army base closed, jurisdiction over the Presidio was transferred to the NPS in 1994. In 1998, management of non-coastal areas of the Presidio was transferred to the Presidio Trust. It is now part of the Golden Gate National Recreational Area. This park is located in the ultra-urban context (population over seven million) of the San Francisco Bay area.

The Presidio Trust has established an implementation plan with its Environmental and Planning Documents, which include a Vegetation Management Plan that defines the goals and objectives for the restoration of the Presidio site to a naturalized landscape. The impetus addressed in these documents includes the need for sustainability and conservation. The management plan promotes "recycling of plant material, wood utilization, efficient use of natural resources (such as water for plant maintenance), and the longevity and maintenance requirements of plants selected for replacement planting" (*22*).

Their guidance document outlines some of the sustainable principles and practices for the large site. The Vegetation Management Plan document is designed to maximize sustainable practices through the following actions:

- Ensure that landscape management projects are consistent with all applicable cultural and natural resource management guidelines and approved plans to minimize impacts.
- Minimize the need to rehabilitate landscape vegetation by maximizing the use and promoting the longevity of existing plant materials.
- Minimize impacts of landscape vegetation on adjacent native plant communities and the historic forest by selecting non-invasive plants with respect to the principles and conditions of sustainable landscapes.
- Minimize the development of landscapes that require intensive ongoing maintenance and energy expenditures. Plants should be selected that are disease and pest resistant, are water efficient or drought tolerant, are adapted to the site's microclimate, and require minimal ongoing maintenance. The natural growth rate and size characteristics of plants should complement the site. Pruning and guying requirements should be minimal.
- Minimize storm water runoff by maximizing groundwater percolation and storm water drainage at each project site. Implement a thorough site grading and drainage plan utilizing appropriate drainage design measures. Promote groundwater percolation through soil de-compaction and specification of permeable ground cover materials.
- Minimize the export of waste materials by maximizing the reuse of existing landscape materials (recycled asphalt, concrete, chipped mulch, compost, etc.).

- Minimize use of chemical fertilizers, pesticides, and herbicides by maximizing the use of natural processes that provide these functions such as integrated pest management, composting, and mulching (22).

The Presidio faces many challenges in implementing this plan. The constraints of historical properties, endangered species, the NPS, and proximity to an ultra-urban condition impact the process:

> Sustainable landscapes reflect principles of conservation and an explicit acknowledgment that natural and cultural resources must be preserved, strengthened, and perpetuated. By stressing the interrelatedness between humans and their environment, it is possible to create a landscape that strikes a balance between human resource consumption and resource conservation. However, achieving sustainable landscapes in an urban environment often presents a challenging task for resource managers.
>
> Humans directly benefit from living proximate to sustainable urban landscapes and natural areas. Improved air quality, recreation, inspiration opportunities, noise abatement, wind reduction, erosion control, watershed protection, wastewater management, and air pollution control are all associated with urban landscapes that are managed according to the conditions of sustainability. When sustainable practices guide the management of urban natural areas, humans gain an appreciation of, and respect for, the interrelationships of all contributing parts to natural systems, including their own cultural context. Though the rationale for promoting sustainable urban natural areas is straightforward, the implementation of associated resource management objectives is far more challenging (22).

The National Park Service has been using organic amendments in their parks for decades. One of the first successful large-scale uses was in 1973 on a 40-acre site in Washington, D.C. The site had soil that was very compacted, "hard as concrete." The Park Service staff used 9400 cubic yards of compost to alleviate the soil compaction. The compost, derived from digested sewage sludge, wood chips, and leaf mold, was tilled to a depth of two feet. Additional topsoil, fertilizer, and wood chips were also used. According to the data, "the compost use in this project not only improved the quality of the existing soil, but also saved taxpayers over $200,000." Park Service staff also reviewed other options for remediating the soil at the park, including the purchase of topsoil to spread over the existing poor soil: "If the Park Service staff had chosen to use topsoil, the cost of the project would have doubled" (*23*).

Golf Courses

One unexpected area that has experienced growth in sustainable landscapes is golf courses. These are historically known for their maintenance intensive, highly manicured landscapes. However, a number of golf courses in Texas and nationwide participate in the Audubon International environmental program for golf courses. The Audubon International program has two designations for courses. The first designation is the signature status, which is awarded only to new developments that are designed, constructed, and maintained according to Audubon International's precise planning standards and environmental disciplines. Wildlife conservation, habitat enhancement, resource conservation, and environmental improvement are integral parts of project development, and regular reports and site audits are required to maintain the certification. The second designation is the Audubon Cooperative Sanctuary Program for Golf Courses (ACSP). The ACSP is for existing courses that convert to environmentally friendly practices. This designation requires participating courses to implement practices that enhance existing habitat, promote wildlife habitat, reduce chemical usage, utilize integrated pest management techniques, practice water conservation techniques, and promote water quality practices.

The first municipal course in the nation to be given Audubon Signature Status by Audubon International was the Tierra Verde Golf Course in Arlington, Texas. Tierra Verde was also the national overall winner of the *Golf Digest* co-sponsored Environmental Leaders of Golf Award in 2004 (*24*). Superintendent Mark Claburn feeds his tees, fairways, and greens with mostly organic fertilizers, including processed poultry manure and corn-gluten meal. His shop contains a "microbrewery" that breeds EPA-approved biofungicide microbes that are routinely sprayed on the greens to gobble up dollar spot and other fungal diseases. Claburn's staff also sprays fermented compost water to oxygenate plants and uses vinegar to eradicate *Poa annua* from Bermuda fairways (*25*).

The Padre Isles Country Club in Corpus Christi, Texas, operated as a traditional club for over 20 years. In the late 1990s the club converted to an ACSP course. The conversion included allowing intensively maintained areas to become native grass and plant areas. The native areas as shown in Figure 5.7, which are now no mow areas, cover approximately 50 acres of the course. The naturalized area of the course has attracted and provided habitat for area wildlife (see Figure 5.8). Currently the only maintained area of the course is the actual greens and fairways as shown in Figure 5.9. The course has also converted to using only tertiary treated effluents for watering and environmentally friendly methods of maintaining the course. The golf course management estimates a savings of over $100,000 per year. The savings comes from reduced water usage, fertilizer, mowing, equipment, and manpower (*26*).

Figure 5.7. View of Padre Isles Golf Course Native Grass Area.

Another Audubon Signature course is the Fazio Canyons course at the Barton Creek Resort and Spa in Austin, Texas. Fazio Canyons is the first Texas resort course to achieve Signature status. The other three golf courses, Fazio Foothills, Crenshaw Cliffside, and Palmer Lakeside, at Barton Creek are ACSP courses. Other ACSP courses in Texas include: the Mesquite Grove Golf Course at Dyess Air Force Base in Abilene, the Clubs at Lakeway in Austin, Kingwood Country Club in Kingwood, Lakeside Country Club in Houston, the Club at

Carlton Woods in the Woodlands, Timmarron Country Club at Southlake, the Hyatt Regency Hill Country Resort in San Antonio, and La Cantera Golf Club in San Antonio.

Figure 5.8. Great Blue Heron on Padre Isles Course.

Figure 5.9. View of Tee Box at Padre Isles.

The government has also used innovative techniques for their golf courses by using a mixture of compost and bulking agents such as aged crumb rubber and wood chips. After years of chemical fertilizers, the soils had become compacted, which reduced the vigor of the turf grasses. To try to alleviate the problem, the U.S. Army Golf Course Operations Division at Fort George Meade, Maryland, and the EPA conducted a 3-year demonstration project in 1995 to determine whether the use of compost amended with crumb rubber could reduce their soil compaction, erosion, and turf disease problems. Locations on the course were chosen because of heavy compaction due to traffic and water runoff. The compost mixture was tilled into the existing soil to a depth of about 5 inches and then seeded with their turf seed. The problems of erosion and compaction in the treated areas were mitigated, and turf grass grew well. Other similar research at the U.S. Air Force golf course in Colorado Springs, Colorado, showed that using the compost/crumb rubber mix reduced irrigation, fertilizer, and pesticide use by 30 percent as compared to their conventionally maintained turf areas *(23)*.

As demonstrated in this chapter, there is clearly a movement at the local, state, and federal level to implement techniques in large scale landscape development that require less energy input. The public is beginning to accept the aesthetics of a more naturalized looking landscape, even in landscapes that have historically had a manicured appearance, such as golf courses. Highway rights-of-way are a good application for the sustainable landscape development.

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CHAPTER 6:
COST AND BENEFIT ANALYSES FOR SUSTAINABLE LANDSCAPES

COST-BENEFIT ANALYSIS (CBA) STUDIES IN CALIFORNIA

Studies have been conducted in the San Joaquin Valley, Coastal Southern communities, and Inland Empire communities (*1,2*) on tree guidelines, and in the Northern Mountain and Prairie region of the United States (*3*) on benefits and costs of strategic tree planting. Cost-benefit analysis of urban landscaping trees was also published by Nguyen (*4*) for ten urban landscaping trees used in Berkeley, California. The United States Department of Agriculture Forest Service and the Houston Green Coalition also sponsored an analysis of urban ecosystems for the Houston Gulf Coast region (*5*). Key findings of these studies are presented in this chapter.

McPherson et al. (*1,2,3,6*) identified the benefits and costs associated with urban landscaping in California. The researchers listed planting cost, pruning cost, tree and stump removal cost, pests and disease control cost, irrigation cost, and other costs that include litter and storm cleanup, litigation/liability, and inspection costs (Table 6.1). The benefits associated with urban tree planting were listed as: energy savings, atmospheric carbon dioxide reduction, air quality improvements, storm water runoff reduction, and aesthetics (Table 6.2). Equations and methods for estimating these costs and benefits were also presented. The average annual costs and benefits in dollars per tree as reported by McPherson 2003 (*7*) are shown in Tables 6.1 and 6.2. The benefits were calculated based on models that connected benefits with tree size variables, i.e., leaf surface area and diameter at breast height (dbh = diameter measured at 4.6 feet above the ground). Information in these tables demonstrates the costs and benefits for landscapes that use native trees in the design. These tables compare local data to data used by McPherson et al.

Table 6.1. Average Annual Costs in Dollars per Tree (7).

Plant	Prune	Remove	Plant	Root related	Storm/liability	Other	Total
Hackberry	29.30	1.43	0.01	0.88	0.76	0.29	32.67
Camphor	8.34	1.78	1.05	0.14	0.00	0.09	11.40
Modesto ash	45.22	0.83	0.01	1.43	0.37	0.93	48.79
Ginkgo	6.56	3.42	2.18	0.75	0.24	0.14	13.29
Sweetgum	49.70	0.90	0.03	2.14	0.62	0.92	54.31
Southern magnolia	17.38	1.13	0.03	0.95	0.70	0.19	20.38
Pistache	25.06	1.54	0.39	0.44	0.19	0.16	27.78
Plane	6.14	0.59	0.51	0.27	0.02	0.13	7.66
Pear	18.55	1.27	0.20	0.53	0.26	0.12	20.93
Zelkova	16.01	2.60	0.78	1.09	0.42	0.24	21.14

Table 6.2. Average Annual Benefits in Dollars per Tree (7).

Tree	Energy	Air Quality	CO_2	Storm Water	Aesthetics	Total
Hackberry	118.3	19.82	7.05	8.23	27.69	181.09
Camphor	54.29	7.62	2.85	6.71	11.29	82.75
Modesto ash	97.83	52.61	7.67	11.19	5.67	174.96
Ginkgo	51.51	2.79	5.43	3.27	35.18	98.18
Sweetgum	79.88	10.16	6.29	5.24	31.38	132.95
Southern magnolia	79.44	2.42	2.81	2.79	6.15	93.61
Pistache	65.31	10.27	2.82	3.34	11.03	92.76
Plane	136.76	25.76	4.80	7.59	11.33	186.24
Pear	34.00	2.98	1.95	1.47	14.19	54.59
Zelkova	89.25	8.26	4.69	3.37	18.47	124.05

McPherson et al. (6) also noted that urban trees absorb carbon dioxide (CO_2) for use during photosynthesis with a release of atmospheric oxygen as one of the end products. They also listed the following air quality benefits provided by urban forests:

- absorption of pollutants such as ozone and nitrogen oxides;
- interception of particulate matter, e.g., dust, ash, and pollen; and
- provision of ground cover that lowers local air temperatures.

An earlier 1998 study by McPherson *(7)* estimated that six million trees in urban areas of Sacramento, California, removed about 304,000 metric tones of atmospheric CO_2 annually. The removal of carbon was projected to have an implied value of $3.3 million. Cost-benefits of urban forests were also estimated for the Puget Sound region as representing a value of $19.5 million if the same air had to be cleaned by emissions control technologies *(8)*.

CBA FOR TEXAS AREAS

American Forests *(5)* assessed the effect of loss of tree canopy and its associated values on the urban ecosystem for a period of 27 years (1972 to 1999) on 3.2 million acres of land within a 50-mile radius of Houston. The findings of this study were summarized as follows:

1. Forests in Houston were noted to have declined, while developed areas have expanded.
2. Increased storm water flow was approximately 360 x 10^6 ft^3 during 2-year, 24-hour peak storm events. This effect of vegetation loss was equivalent to a one time savings of $237 x 10^6 to build storm water systems in the area to accommodate excess runoff (estimates from Harris County Flood Control District).
3. When trees were healthy, they improved air quality, reduced atmospheric carbon, slowed storm water runoff, and reduced peak flow *(5)*.

Changes in vegetation in Houston and the associated benefits are listed in Table 6.3. This data indicates that the acreage of land covered by trees decreased significantly between 1972 through 1999. These changes in land coverage equate to $237 million in storm water management value loss and $38 million in air pollution removal value loss *(5)*. Implementation of a sustainable roadside landscape that incorporates native tree plantings will eventually allow the city to recover benefits that were lost due to the decrease in plant cover over the area.

Table 6.3. Houston Area's Vegetation Change and Associated Benefits (5).

	1972	1999	Loss/gain 1972-1999
Acres with more than 50% tree cover	1,004,361 (31%)	844,923 (26%)	-16%
Acres with 20-49% tree cover	188,042 (6%)	86,859 (3%)	-54%
Acres with less than 20% tree cover	2,007,321 (63%)	2,267,942 (71%)	13%
Storm water management value	$1.56 billion	$1.33 million	-$237 x 10^6 total
Air pollution removal value (annually)	$247 million	$209 million	-$38 million
Energy savings*** (annually)		$26 million	0

*** Residential summer energy savings from trees' direct shading of one- and two-story detached residences.

OTHER CBA ANALYSES

A roadside planted with trees and shrubs in Bolingbrook, Illinois, helped filter and infiltrate storm water. Abbot Laboratories planted the 40-acre Abbot Park in Illinois with natural prairie grass. Installation cost for a turf grass was estimated to be about $3500/acre, while the prairie installation was $400/acre. Maintenance costs were $3500/acre for turf and $100/acre for the prairie landscape that provided aesthetic qualities such as leaf and flower size and color as well as bird habitat at the park (*10*).

Annual runoff reductions of two to seven percent were noted during simulation of urban forest effects on storm water by McPherson et al. (*3*), and Xiao et al. (*10*) indicated the annual interception of rainfall in Sacramento's urbanized areas to be about two percent. American Forests (*11*) reported a two percent runoff reduction in the Colorado Front Range with a management value of $3.2 million.

The Union Gas Customer Service Center in Brantford, Ontario, conducted a cost and benefit analysis of their parking lot that has a thriving tall grass plant landscape of restored prairie in the lawns and along the roadside. Their calculations showed that the cost of a conventional landscape was more expensive than the naturalized landscape (*12*). This study established that initial operating and maintenance costs were higher in the natural landscape due to the intensive labor required to get the plants to establish. However, once the plants were established (five to ten years after installation), the operating and maintenance costs were one-third less than the turf grass landscape.

SOIL AMENDMENT COSTS AND VALUES

A Natural Resource Conservation Service (NRC) draft technical note stated that organic soil management is cost-effective in landscape management because it can prevent erosion and help remedy effects of past erosion problems (*13*). Examples were given to show costs associated with routine soil management (Table 6.4).

Table 6.4. Top Soil Management Cost Values (*13*).

Item	Cost/Ton
Cost by the bag	$40-80
Cost by the truckload	$15
Cost to replace soil functions and remedy off-site damage	$19*
Cost of erosion to downstream navigation	$0-5
Cost to human health	$3

* Data adjusted to 1997 dollars

VEGETATION BENEFITS ESTIMATION

The Sacramento Municipal Utility District (SMUD) developed a tree benefit estimator for the American Power Association (APPA). This estimator is a web-based program that quantifies and tracks benefits of planting shade trees in urban or suburban settings (*14*). The authors caution that broad assumptions were made during program development in regard to impact of: a) trees on direct shading benefit, b) indirect/direct evapotranspiration effect, c) heating penalty in winter months, and d) tree growth rates and tree survival rates. These assumptions tended to result in less precise data than a more tailored approach. Data requirements include: tree species, direction of the planted trees to buildings, distance between trees and buildings, and the age of the tree from the planting date. The benefits that are calculated by the tree benefit estimator include:

- amount of energy saved measured in kilowatt-hours (kWh),
- capacity saved measured in kilowatt (kW), and
- carbon and CO_2 sequestration (pounds) that result from matured trees in urban settings.

Tree cover benefits to storm water management, air quality, and energy conservation were analyzed by American Forests for the San Antonio area. The analysis used geographic information systems (GIS) and scientific research to determine the effects of trees on the urban environment. The report noted that trees in the study area reduced storm water runoff volumes by 678 x 10^6 ft^3 during major storms. Construction of retention facilities to handle this runoff could cost $1.35 billion (*15*). This study noted that Greater San Antonio could save more than $70 million annually from urban tree canopy effect on runoff volume.

SUSTAINABLE AND TRADITIONAL LANDSCAPES COMPARISON

Table 6.5 shows a comparison of sustainable (native) and traditional landscape estimates by Conservation Design Forum, Inc., of Elmhurst, Illinois. The comparison is based on a 10-acre corporate landscape. A detailed breakdown of costs was also provided in this article. The authors pointed out that traditional landscape required a wider spectrum of landscape treatments; hence, their up-front investments were greater than that of a new native landscape (*16*). Natural landscapes showed a lower cost of maintenance than traditional landscapes over a long-term. These benefits were derived from the ability of native perennial plants to survive in local environmental conditions such as soil types, surrounding air temperatures, and drought (*17*).

The comparisons noted that the first four to five years of a new sustainable (native) landscape tend to have fairly intensive management due to efforts being made to balance the establishment of native and non-native plants. After the fifth year, the system gets into its own self-growth renewing capabilities, i.e., seasonal renewal by seed and rhizome growth, which result in minimal management. Close attention to management is needed in early stages of establishment of sustainable landscape to ensure proper establishment of the planted native plants. This will require additional seeding of species in areas that may need more plant covering.

Table 6.5. Annual Long-Term Management Costs of Two Landscape Systems (*16*).

Year	Sustainable (Native) Landscape (Annual Cost)	Traditional Landscape (Annual Cost)
Total Upfront Cost	$141,000	$269,000
1	$19,000	$33,000
2	$32,000	$33,000
3	$17,000	$33,000
4	$30,000	$33,000
5	$15,000	$33,000
6	$13,000	$30,000
7	$5,000	$30,000
8	$13,000	$30,000
9	$5,000	$30,000
10	$13,000	$30,000
Total (Maintenance)	$162,000	$315,000

A traditional landscape, however, requires intensive mowing, sod maintenance, weeding, and early plant replacement. The initial cost at this point is similar to the native landscape. However, after about five years, the effects of stresses due to herbicide application, shrub and tree mortality, etc., will result in greater maintenance costs than sustainable (native) landscape. Installation costs of irrigation equipment as well as costs of irrigation water can be very high. This cost is avoided in sustainable landscaping.

SUMMARY OF BENEFITS OF SUSTAINABLE ROADSIDE LANDSCAPES

As stated in Chapter 1, a successful sustainable urban roadside landscape should be able to reduce the energy input of the landscape including maintenance and amendments, have a low chemical dependency, have a cost-effective method of implementation, and are aesthetically pleasing as a natural landscape. A review of the literature indicated that cost benefit evaluations of sustainable landscapes can be divided into major categories: economic and environmental.

Economic

Implementation of sustainable urban roadside techniques will benefit TxDOT in many ways, including economic and environmental. The potential annual savings to departmental budgets could result from:

- reduced maintenance costs:
  - little or no mowing,
  - little or no edging or trimming,
  - little or no chemical fertilizer application, and
  - little or no chemical herbicide application;
- reduced water use:
  - little or no supplemental irrigation, and
  - irrigation during establishment period only.

Since sustainable urban roadway landscapes require little or no irrigation beyond an establishment period or frequent mowing, the installation and maintenance costs for these sites were minimal compared to traditional landscaped sites (Table 6.5). The cost for the first year of a traditional unsustainable landscape was estimated to cost more that 50 percent than that of a prairie landscape (*17*).

An integral part of TxDOT's roadway design process is to reduce the cost of storm water management. Sustainable urban roadside landscapes were found to function as storm water detention, retention or run-off control systems. Planting roadside landscapes was documented to reduce storm water run-off volume minimizing the cost of managing roadway storm water (*17*).

Environmental

Sustainable urban roadway landscapes have the ability to co-exist within the local surroundings with little or no additional maintenance. This type of landscape can reduce stresses on the environment caused by non-sustainable or more traditional landscape maintenance activities that includes a regular chemical regime. The traditional landscape may feature either native or non-native plants, however; they usually require an inordinate amount of care and water to survive or remain viable in health and appearance. These traditional landscapes, turf applications in particular, are heavily dependent on chemical applications. These chemicals are surface applied and the excess chemicals not utilized by the plant materials can be transported by rainfall to storm water conveyance systems and ultimately to adjacent waterways thereby degrading water quality.

Energy input and pollutant output for a sustainable urban roadside landscape is generally far less than that of a more traditional landscape. The reduction in mechanical maintenance could:

- reduce the potential for excess chemical applications reaching receiving waters;
- reduce air pollution from maintenance equipment:
  - less carbon monoxide, volatile organic carbons, and nitrogen oxides; and
- reduce the contribution to ground level ozone (smog) and other particulates.

The root system of plants grown in a natural or amended organic soil structure often grows denser and deeper. The organically amended soil has the potential to:

- increase the ability of the soil to capture and retain moisture;
- increase storm water infiltration and uptake by plant materials:
  - less storm water runoff,
  - less storm water pollutants reaching receiving waters;
- increase soil structure stability:
  - less soil erosion.

In addition to the above mentioned benefits, the public has become very vocal and persistent in its request for state agencies such as TxDOT to be environmentally proactive in their approach to the use of more sustainable landscape techniques.

As stated previously in Chapter 2, the rehabilitation of the soil with organic matter and amendments to generate a sustainable urban roadside landscape will maximize the environmental and economic benefits gained from the soil and vegetation as they reduce erosion control, filter storm water, provide carbon sequestration, and storage capabilities for nutrients, water and air.

CHAPTER 6 REFERENCES

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CHAPTER 7:
FINDINGS AND COMMENTARY

The primary goal of this project was to investigate alternative management practices by the public and private sectors for possible application to urban landscape projects for the Texas Department of Transportation. Specifically, this project included an investigation of current practices for more sustainable roadside landscapes in Texas and other states, including cost and benefit evaluations, and the analysis of traditional and more sustainable landscaping comparisons of maintenance, water use, erosion control, and pollutant runoff mitigation. *Traditional landscaping* is an attempt to create a landscape that looks a certain way regardless of location. In contrast, a *sustainable roadside landscape* requires low energy inputs including maintenance and amendments, has low chemical dependence, has a cost-effective method of implementation, and is as aesthetically pleasing as a natural landscape. In order to support structures and roadways, post highway construction roadside soil conditions are compacted and devoid of organic matter causing significant soil alterations and management to take place to support vegetation establishment. New methods of vegetation establishment for synthesis in this report include naturally derived soil amendments, erosion control through optimal local vegetation establishment practices, and integration into regional ecosystems.

A sustainable roadside landscape must be maintained within the constraints of its location and environment with low energy input, low chemical application dependency, be cost effective in implementation, and aesthetically acceptable. This report includes information about public and private sector experiences in search of more sustainable landscaping practices. The science of determining cost savings and life cycle assessment of more sustainable landscaping is becoming better understood and more precise. Sustainable landscapes appear to be more robust, more biodiverse, develop a stronger native seed bank, and are able to retain more moisture and nutrients than other approaches. The soil condition and foundation for vegetation establishment remains critical for transportation project disturbed soils especially for factors such as nutrient release, tilth and microbial activity. Naturally-derived and humic-based carbonaceous soil amendments can provide the improvements to soil structure not realized with just synthetic fertilizer additions. Organic additives can provide adequate nutrients at startup, more timed release of growth essentials, NPK over the growing season, bind chemicals from excessive runoff, and reduce storm water runoff pollution

The addition of organic amendments to roadside landscape development projects offers advantages in the form of a slower, more timed release of nutrients than synthetic quick release fertilizers or amendments. While composted materials can provide a carbon source and soil organic matter, they contain much lower levels of nutrients than prepared fertilizers. This can be a disadvantage of these materials when a quick release of nutrients for rapid plant growth is needed, however. The organic amendments can also present less risk for storm water runoff pollution and over-fertilization of new plants. The organic amendments have the advantage of adding real improvement to soil structure in a manner not possible with non-organic or chemical additives and have been proven to be successful in several large- and small-scale projects.

The re-establishment of the mycorrhizal fungi, soil bacteria, and other beneficial soil organisms is an integral part of restoring highly disturbed soils. This can be accomplished through the incorporation of certain organic complexes such as humic acid, enzymes, and bacteria, along with rich, organic nutrients, such as compost. Such amendments will stimulate the growth of soil organisms in order to nourish and sustain vegetation.

Many of the organic and mineral amendments and techniques examined by the project team may be amenable to residential and commercial applications where experimentation and close monitoring of vegetation are possible but do not appear to be practical for large-scale roadside landscapes. Many of the products available include elaborate mixtures and recipes for application of specialty products such as worm castings and various compost tea brews. However, there may be some practical applications in urban settings where right-of-way spaces are limited.

A major problem encountered in large-scale utilization of organic amendments is the quantity and packaging of the products. Many of the products have been proven beneficial and desirable for use on the highly disturbed right-of-way soils; however, distribution packaging of many products precludes its use at the scale of the roadside landscape development. These urban roadside projects vary in size from small planting beds to multi-acre interchanges. However, as with any commercially available product, there is a supply and demand component. These products will enhance the soil and enable TxDOT to implement a sustainable roadside landscape. As they are used in select project locations, bulk product distribution will likely follow. This was demonstrated when TxDOT began using compost on the roadside. Initially, product availability, distribution, and quality control were issues. As TxDOT continued to specify compost on numerous projects throughout the state, the producers and distributors followed suit with supply.

As with many DOTs, sustainable landscapes are becoming a necessity. Several TxDOT districts have developed innovative landscape efforts specifically to establish sustainable landscapes that require little if any supplemental water and utilize very little chemical fertilizers. The newer landscapes have high moisture retention potential, more effective erosion control and diverse soil microbial ecology. TxDOT has already used over two million cubic yards of compost in its construction and maintenance activities. Other organic amendments and additives may need to have the same demonstration and implementation procedures as compost has had for the past several years. The Houston, Dallas, and Austin Districts have implemented many of the organic amendment techniques with some successes, where the projects have remained aesthetically pleasing with little or no maintenance. As these methods evolve, improved maintenance cost savings and public acceptance is anticipated at even higher levels in the near future. Questions and concerns remain in terms of the longevity of applications and actual reduction of costs associated with the maintenance of the amended landscaped areas. TxDOT should consider the implementation of a monitored in-situ project that tracks data from a sustainable landscape from installation through a three- to five-year period.

APPENDIX A:
GLOSSARY OF TERMS

The following is a compilation of terms pertinent to sustainable roadside landscaping.

Abatement—The reduction of the degree or intensity of pollution or the elimination of pollution.

ADP—Adenosine di-phosphate, which is a high energy phosphate molecule involved in the production and storage of energy.

Audubon Cooperative Sanctuary Program (ACSP)—A joint program between Audubon International and the United States Golf Association that promotes ecologically sound land management and conservation for golf courses. There are six categories required for recognition: environmental planning, wildlife and habitat management, chemical use reduction and safety, water conservation, water quality management, and outreach and education. There are two levels of participation: the ACSP level, which is available to existing and new courses, and the Audubon Signature level, which is available only for new courses.

ATP—Adenosine tri-phosphate, which is a high energy phosphate molecule required to provide energy for cellular function.

Beneficial Landscapes—Beneficial landscaping is the practice of incorporating the following principles in practices in landscaping: protect existing natural areas, use regionally native plants, reduce turf, reduce pesticide use and practice IPM, compost and mulch, practice soil and water conservation, reduce power landscape equipment, use trees or plants to reduce heating/cooling requirements, avoid invasive plants, and create additional wildlife habitat.

Best Management Practices (BMP)—Conservation measures intended to minimize or mitigate impacts from a variety of land use activities (*1*).

Biodiversity—The variety and variability among living organisms and the ecological complexes in which they occur.

Bioengineering—In soil applications, refers to the use of live plants and plant parts to reinforce soil, serve as water drains, act as erosion prevention barriers, and promote dewatering of water laden soils.

Biofilters—A filtration system using natural or biological matter. Biofilters are used in storm water and runoff filtration, air pollution filtration, and aquaculture.

Bioretention—The use of a vegetated depression that is designed to collect, store, and infiltrate runoff as a means of storm water management. The vegetated depression typically includes a mix of amended soils and vegetation.

BOD—Biochemical oxygen demand, which is the amount of oxygen used when organic matter undergoes decomposition by microorganisms.

Cation Exchange Capacity (CEC)—A measurement of a soil's ability to bind positively charged ions (cations), which include many important nutrients. Depends on the amount and type of clay and the amount and humification of organic matter in soil. Most of the major cation nutrients are held in the soil by CEC (calcium, magnesium, and potassium).

Chemical Fertilizers—A synthetic or manufactured substance that is added to the soil to supply essential elements for plant growth. Chemical fertilizers generally release nutrients faster than naturally occurring fertilizers. However, over-application of chemical fertilizers may result in contamination of runoff water and plant burn.

Compost—The material that results from the composting process is a dark, moist, soil-like substance that enriches the nutrient content of soil and helps soil structure. If it is produced mainly from plant residue, it may be called "artificial manure" or "synthetic manure." The addition of compost as a soil amendment is used for erosion control and for providing nutrients to the soil. Using compost to amend soils assists the soil in filtering and breaking down urban pollutants such as hydrocarbons, heavy metals from cars, and pesticides or soluble fertilizers applied to landscapes.

Composting—The controlled breakdown or decomposition of organic materials under aerobic (i.e., with air) or anaerobic (i.e., without air) conditions. Composting allows the good "bugs" to wipe out the "bad" bacteria. Composting includes organic residues, or a mixture of organic residues and soil, that have been piled, moistened, and allowed to decompose. Mineral fertilizers are sometimes added.

Compost Tea—A low nutrient liquid that results from placing slightly soluble humics or compost in water.

EPA—Environmental Protection Agency.

Erosion—The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. Erosion levels vary greatly with topographic variations and land use patterns.

Erosion Impacts on Soil—Erosion impacts various soil types differently because of the varying characteristics of each soil type. Soil characteristics that determine erosion levels include top soil thickness, texture distribution, rooting depth, soil density, soil fertility, and slope.

Fertilizer—Any organic or inorganic material of natural or synthetic origin that is added to a soil to supply certain elements essential to the growth of plants.

FHWA—Federal Highway Administration.

FT-IR—Fourier transform infrared, which is a measurement technique whereby spectra are collected based on measurements of the temporal coherence of a radioactive source, using time domain measurements of the electromagnetic radiation or other type of radiation.

Fulvic Acid—The pigmented organic material that remains in solution after removal of humic acid by acidification. Fulvic acid is soluble in alkali, acid, methyl ethyl ketone, and methyl alcohol.

Green Sand—Moist sand that is bonded by a mixture that contains silica, bentonite clay, carbonaceous material, and water.

Green Waste—Green waste is an organic material that is easily returned to the soil. It normally includes grass cuttings, garden clippings, pruning debris, weeds, leaves, dead plant material, and soil-bound roots.

Groundwater Infiltration—The process by which water on the surface filters through the soil layers. The speed of infiltration depends on soil moisture, soil type, and its infiltration capacity. Having infiltrated, water becomes either soil moisture within the vadose zone or groundwater in an aquifer.

Gumbo Clay—A very sticky black, gray, or green-colored clay soil commonly found throughout the southern half of the United States. The high percentage of clay particles in the soil swells to form an impermeable layer when satiated. This type of soil is easily compacted and often requires heavy amendments for sustained plant growth.

Hard Pan—A naturally formed layer of hard soil that roots cannot penetrate and that water cannot drain through. Hard pan is attributed to dry, cohesive soils with narrow particle-sized distribution and minimal available pore space.

Humates—The salts found in humic acid.

Humic Acid—Humic acid is a complex mixture of organic acids produced mostly by the decomposition of plant material, especially lignin. Humic acid is dark brown and is a major constituent of humus. It can also be found in peat, coal, and ocean water.

Humin—A part of organic soil compounds that does not dissolve when treated with diluted alkali solutions.

Humus—A dark, loamy, organic material resulting from the decay of plant and animal refuse. Generally, the decomposition has proceeded sufficiently to make it impossible to recognize the original material.

Integrated Pest Management (IPM) —Integrated pest management is a strategy that relies primarily on non-chemical means to prevent and manage pests. These non-chemical means could include controlling climate, food sources, and building entry points, or even introducing competing species. It is not meant to eradicate all pests but merely to eliminate insect, disease, and weed pest problems. Benefits of IPM include reducing risks associated with chemical pesticide use and delaying pest resistance.

Lava Sand—Crushed scoria, a reddish brown to black volcanic slag. It has a texture full of holes. Lava sand makes soil nutrients more available to plant roots by providing aeration and porosity to the soil. It helps retain the right amount of moisture in the soil, is durable, and resists degradation.

Leachate—Liquids that have percolated through a source such as soil or compost and that carry soluble and non-soluble substances via solution or suspension.

Lignin—A naturally occurring substance in plants that is responsible for their strength. Lignin is the chief constituent of wood other than carbohydrates; it binds to cellulose fibers to harden and strengthen the cell walls of plants.

LID—Low impact development is an approach to comprehensive land planning and engineering design that has a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds.

Macronutrient—A chemical element that is necessary in large amounts for the growth of plants. Macronutrients are usually found composing 0.1 percent or more of the plant's dry weight. "Macro" refers to the quantity and not to the essentiality of the element to the plants.

Manure—The excreta of animals, with or without the admixture of bedding or litter, in varying stages of decomposition. It is also called barnyard manure or stable manure (*2*).

Micronutrients—A chemical element that is necessary in only small amounts for the growth of plants. Macronutrients are usually found composing less than 0.1 percent of the plant's dry weight. "Micro" refers to the quantity and not to the essentiality of the element to the plants.

Mineralization—The breakdown and conversion of organic compounds into inorganic minerals. Mineralization is the process by which organic residues in the soil are broken down to release mineral nutrients that can be utilized by plants.

Mulch—Any material such as straw, grass clippings, sawdust, leaves, loose soil, or shredded garden wastes that is spread on the surface of the soil to protect the soil and the plant roots from the effects of raindrops, soil crusting, freezing, and evaporation. The texture of the mulch depends on the coarseness of the mulched material. It is commonly used as a form of water conservation.

Native Vegetation—Vegetation that is indigenous to a particular area or region. It may also be referred to as natural vegetation.

Naturalization—The practice of designing, cultivating, and maintaining plant communities that are native to the bioregion with minimal resort to artificial methods of plant care such as chemical fertilizers, watering other than natural precipitation, and mowing.

Natural Landscaping—An approach often called native landscaping or even beneficial landscaping. It emphasizes the use of native plants and natural materials. These natural landscaping techniques have numerous advantages over conventional and highly engineered site management techniques. Natural landscaping is based upon natural attributes and natural processes that result in: (1) reduced landscape installation and maintenance costs, (2) avoidance of the use of lawn chemicals such as fertilizers and herbicides, (3) reduced or eliminated costs for irrigation systems, (4) improved habitat and increased biodiversity, (5) distinctive and attractive sites, (3) improved water quality and reduced damages from storm water, (4) improved outdoor recreation and education opportunities, and strengthened stewardship of the environment by people *(4)*.

NRCS—Natural Resource Conservation Service.

Organic—For the purposes of this project, defined as non-chemical in relation to soil and plant treatments and amendments. It is preferable to use the term non-chemical.

Pesticides—Any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. Though often misunderstood to refer only to insecticides, the term pesticide also applies to herbicides, fungicides, and various other substances used to control pests. Under U.S. law, a pesticide is also any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant *(5)*. Pesticides may be chemically based or biologically based. Biologically-based pesticides include pheromones and microbials.

PI—Plasticity index, which is a numerical measure of the expansiveness or plasticity of a soil. It corresponds to the range of moisture contents, expressed as percent water by dry weight of soil, within which the soil has plastic properties.

Plant Available Water—That part of the water in the soil that can be taken up by plant roots.

Pollutant—The introduction of an unwanted material to the air, water, or soil which makes them impure or unclean, or causes harm to an area of the natural environment.

Pore Space—The void area between soil solids, which is occupied by air and water. Heavily compacted soils have reduced pore space, while soils with tilth have large pore spaces.

Reforestation—The natural or artificial restocking of an area with forested trees *(1)*.

Restoration—The return of an ecosystem to a close approximation of its condition prior to disturbance *(1)*.

Revegetation—The deliberate process of reintroducing plants in an area where plant cover has been removed. Revegetation contributes to vegetation cover when the species composition and structure (i.e., all vegetation strata) are similar to pre-existing vegetation types for that area.

Runoff—The portion of the total precipitation or irrigation water that flows off the land into drainage or stream channels. Surface runoff does not enter the soil but can carry pollutants from the air and land into receiving waters.

Slope Stabilization—The resistance of a natural or artificial slope or other inclined surface to failure by mass movement. When properly installed and maintained, vegetation can protect slopes by reducing erosion, strengthening soil, and inhibiting landslides, thus increasing general slope stability.

Soil Aeration—The process by which air in the soil is replaced by air from the atmosphere. In a well aerated soil, the soil air is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen than the atmosphere. The rate of aeration depends largely on the volume and continuity of pores in the soil.

Soil Amendments—Any material that is worked into the soil to enhance the soil's properties. There are two types of amendments: organic and inorganic. Examples of organic amendments include organic matter such as compost, peat moss, manure, bone meal, and leaf mold, while inorganic amendments would include vermiculite, perlite, tire chunks, pea gravel, and sand.

Soil Bulk Density—The mass of dry soil per unit bulk volume. The bulk volume is determined before the soil is dried to a constant weight at 105°C.

C:N Ratio—The ratio of the weight of organic carbon to the weight of total nitrogen in a soil or in an organic material. It is obtained by dividing the percentage of organic carbon (C) by the percentage of total nitrogen (N).

***Soil Amendments*—**Additives to the soil that provide the capability to retain moisture, improve drainage, provide nutrients, and improve the soil texture.

Soil pH Levels—The degree of acidity or alkalinity of a soil, expressed in terms of the pH scale. A pH of 7 is neutral. Acidic soils have a pH less than 7, and alkaline soils have a pH greater than 7.

Soil Moisture—The ability of a soil to hold water, including water vapors, which are pressed into the pores of a soil. Soil moisture impacts the distribution and growth of vegetation, soil aeration, soil microbial activity, soil erosion, the concentration of toxic substances, and the movement of nutrients in the soil to the roots. Soil compaction can affect the capability of the soil to hold moisture.

Soil Restoration—The return of a soil to a close approximation of its condition prior to disturbance.

***Soil Stabilization*—**Chemical or mechanical treatment designed to increase or maintain the stability of a mass of soil or to otherwise improve its engineering properties

***Soluble Minerals*—**Naturally occurring substances capable of being dissolved.

Sustainable—The ability to maintain or preserve in spite of external pressures.

Sustainable Landscape—Definitions vary, but sustainable landscaping should include an attractive environment that is in balance with the local climate and requires minimal resource inputs, such as fertilizer, pesticides, and water. Sustainable landscaping begins with an appropriate design that includes functional, cost efficient, visually pleasing, environmentally friendly, and maintainable areas (*3*).

TCEQ—Texas Commission on Environmental Quality.

Tilth—The physical condition of the soil as relative to plant growth. Soil tilth is a factor of soil texture, structure, and the interplay with organic content and the living organisms that help make up the soil ecosystem.

TMDL—Total maximum daily load, which is the maximum amount of a pollutant that can be discharged into a water body from all sources (point and non-point) and still maintains water quality standards.

Traditional Landscaping—Landscaping that relies heavily on cultivation of ornamentals, bedding plants, and heavily manicured turf grasses.

TxDOT— Texas Department of Transportation.

USDA—U.S. States Department of Agriculture.

Water Holding Capacity—The amount of water in soil that can be absorbed by plants, between the high amount at full satiation or field capacity and the low amount at the permanent wilting capacity.

Weed Management—Any undesired plant is termed a weed. Weed management deals with controlling and preventing the growth of weeds. Weeds may be classified as grasses, sedges, and broadleaf weeds.

APPENDIX A REFERENCES

1. Texas Parks and Wildlife Department. "Glossary of River Terminology." Published online at http://www.tpwd.state.tx.us, accessed August 2006.

2. National Land and Water Information Service. *Glossary of Terms.* Canadian Agriculture and Agrafood. Published online at http://sis.agr.gc.ca/cansis/glossary/, accessed August 2006.

3. J. Bousselot, K. Badertscher, and M. Roll. *Sustainable Landscaping*. Colorado State University Cooperative Extension Horticulture. Published online at http://www.ext.colostate.edu/PUBS/GARDEN/07243.html, accessed August 2006.

4. EPA. *Green Landscaping: Green Acres, A Natural Landscaping Toolkit*. Published online at http://epa.gov/greenacres/, accessed August 2006.

5. EPA. *About Pesticides.* Published online at http://epa.gov/, accessed August 2006.

APPENDIX B:
ADDITIVES—ORGANIC FERTILIZERS AND AMENDMENTS

Appendix B is adapted from Austin Organic Gardeners, *Organic Amendments and Fertilizers* *(1)* and Whiting, et al. *Organic Fertilizer*, from Colorado State University Cooperative Extension *(2)*. This list does not endorse any product, additive or amendment.

Alfalfa Meal/Pellets

Product components	dried alfalfa
Typical NPK analysis	2-1-2, up to 3% N
Release time	1–4 months
Advantages	contains triacantanol plant growth factor for nutrient uptake high availability of trace elements may suppress and control certain fungal diseases
Disadvantages	
Application	1–10 lb/100 square feet (SF)

Blood Meal

Product components	dried animal blood
Typical NPK analysis	12-0-0, up to 15% N
Release time	3–4 months
Advantages	contains plant growth regulators
Disadvantages	can burn plants if misapplied
Application	1–10 lb/100 SF

Bone Meal

Product components	steamed and ground animal bones
Typical NPK analysis	3-15-0 and 24% calcium
Release time	6–12 months
Advantages	available phosphorus in soil with pH below 7.0
Disadvantages	can be expensive
Application	1–10 lb/100 SF incorporated into soil

Calcium Carbonate

Product components	finely ground calcitic limestone
Typical NPK analysis	32–40% calcium
Release time	slow
Advantages	adds organic matter to soil
Disadvantages	
Application	8 lb/100 SF clay soil, 6 lb/100 SF loams, and 2 lb/100 SF sands incorporated into soil

Corn Gluten/Meal

Product components	ground corn
Typical NPK analysis	9-0-0 and trace elements including sulfur

Release time	over 4 months
Advantages	weed control
Disadvantages	can be expensive
Application	5 lb/100 SF

Cottonseed Meal

Product components	byproduct from food grade cottonseed oil production.
Typical NPK analysis	varies 6-1-1 to 7-2-2
Release time	1–4 months
Advantages	
Disadvantages	may have pesticide residue from crop production
Application	5–10 lb/100 SF

Dolomite

Product components	finely ground calcium magnesium limestone
Typical NPK analysis	35–46% magnesium carbonate, 6–11% magnesium, 22% calcium
Release time	several years
Advantages	will raise soil pH
Disadvantages	will raise soil pH
Application	8 lb/100 SF clay soil, 6 lb/100 SF loams, and 2 lb/100 SF sands incorporated

Epsom Salts

Product components	magnesium sulfate
Typical NPK analysis	10% magnesium and 13% sulfur
Release time	quick
Advantages	water soluble sulfate mineral
Disadvantages	
Application	1–4 lb/100 SF

Feather Meal

Product components	byproduct of poultry slaughter industry
Typical NPK analysis	7–12% N
Release time	more than 4 months
Advantages	slow release
Disadvantages	
Application	2.5–5 lb/100 SF

Fish Meal/Emulsion

Product components	dried and ground fish parts
Typical NPK analysis	for meal it varies 5-3-3 and 10-6-2, micronutrients for acid digested emulsion 4-4-1 for enzyme digested emulsion 4-1-1
Release time	1–4 months
Advantages	meal can be good nitrogen source
Disadvantages	emulsions may contain synthetic fortifiers
Application	5–10 lb/100 SF

Granite Meal (Granite Dust)

Product components	ground granite
Typical NPK analysis	3–5% potassium, 67% silica (sand), micronutrients
Release time	10 years
Advantages	slow release
Disadvantages	needs to be finely ground to be useful
Application	2.5–10 lb/100 SF broadcast

Greensand (Glauconite)

Product components	dried ocean deposits
Typical NPK analysis	5–7% potassium, trace minerals, silica
Release time	10 years
Advantages	
Disadvantages	
Application	2.5–10 lb/100 SF

Guano

Product components	powdered bat manure
Typical NPK analysis	10-3-1 or 3-10-1 depending on source
Release time	over 4 months
Advantages	trace elements
Disadvantages	can be expensive
Application	5 lb/100 SF

Gypsum

Product components	calcium sulfate powder
Typical NPK analysis	22% calcium, 17% sulfur
Release time	slow
Advantages	can neutralize excessive sodium, plant toxins, reduce compaction
Disadvantages	
Application	.5–4 lb/100 SF incorporated depending on soil calcium

Humate

Product components	humic and fulvic acids from leonardite, lignite coal, and clay
Typical NPK analysis	60% humic and fulvic acids
Release time	quick
Advantages	increase phosphate and micronutrient uptake, root development
Disadvantages	not all humates are the same

Kelp/Cytokinin (Seaweed)

Product components	dried seaweed
Typical NPK analysis	minimum 2% potassium, micronutrients
Release time	over 4 months

Advantages	may contain amino acids, vitamin, growth hormones, anti-fungal agent solid form adds organic matter to soil
Application	Solid 1–10 lb/100 SF, liquid as directed

Langbeinite (Sulfate of Potash Magnesia—Sul-Po-Mag and K-Mag)

Product components	
Typical NPK analysis	potash content—langbeinite 22%, potassium sulfate 50%
Release time	quick
Advantages	
Disadvantages	avoid excessive magnesium application
Application	1 lb/100 SF

Lava Sand

Product components	waste material from lava gravel
Typical NPK analysis	trace elements
Release time	slow
Advantages	
Disadvantages	
Application	1–4 lb/100 SF

Molasses

Product components	molasses
Typical NPK analysis	sulfur, potash, and trace elements
Release time	1-4 months
Advantages	stimulates microorganisms
Disadvantages	can be expensive
Application	liquid or powder

Rock Phosphate/Colloidal Phosphate/Calcium Phosphate—Calphos

Product components	crushed and washed rock
Typical NPK analysis	20% calcium, 3% available phosphoric acid
Release time	slow
Advantages	economical
Disadvantages	
Application	1–6 lb/100 SF incorporated

Soybean Meal

Product components	byproduct of soybean oil extraction
Typical NPK analysis	7-1-2
Release time	1–4 months
Advantages	
Disadvantages	can be expensive
Application	8 lb/100 SF

Sphagnum Peat Moss

Product components	harvested peat
Typical NPK analysis	
Release time	
Advantages	increases water holding capacity
Disadvantages	some sphagnum can contain harmful to human fungus
Application	

Sulfur

Product components	sulfur powder
Typical NPK analysis	100% sulfur
Release time	quick
Advantages	reduces pH, can be insecticide and fungicide
Disadvantages	
Application	1 lb/100 SF incorporated into 3 inches of soil to lower soil pH one point

Worm Castings

Product components	worm manure
Typical NPK analysis	some nitrogen, phosphorus, calcium, magnesium, and potassium
Release time	slow
Advantages	beneficial bacteria, reduces compaction, adds organic matter
Disadvantages	
Application	25 lb/100 SF to soils low in organic matter 10 lb/100 SF to soils with a moderate amount of organic matter 5 lb/100 SF to soil with adequate organic matter

Zeolites

Product components	alumino-silicate clay mineral with rigid crystalline structure
Typical NPK analysis	
Release time	slow
Advantages	high CEC, nutrient and moisture holding capacity
Disadvantages	
Application	1–6 lb/100 SF incorporated

APPENDIX B REFERENCES

1. Austin Organic Gardeners. *Organic Amendments and Fertilizers*. Published online at http://www.main.org/aog/articles/fert.htm, accessed June 2006.

2. D. Whiting, C. Wilson, and A. Card. *Organic Fertilizers*. Colorado State University Cooperative Extension. No 7.733. Published online at http://www.ext.colostate.edu/PUBS/GARDEN/07733.html#corn, accessed February 2006.

APPENDIX C:
SOURCES OF ORGANIC PRODUCTS/SUPPLIERS/MANUFACTURERS

This list of Sources of Organic Products/Suppliers/Manufacturers does not endorse any product, additive or amendment. The list does not endorse any supplier, manufacturer, or distributor and is not a complete listing of available sources of organic products, suppliers or manufacturers. It is intended as a representative sample of sources throughout Texas.

Advanced Microbial Solutions
801 Hwy 377 South
P.O. Box 519
Pilot Point, TX 76258
940-686-5545
940-686-2527 (Fax)
E-mail: superbio@superbio.com
http://www.superbio.com

Product Categories: Microbial Inoculants

- SuperBio® SoilLife™
  - SuperBio microbes, humic acid, and 3% nitrogen (derived from urea ammonium nitrate)
- SuperBio® Microbes™
  - a fermented product derived from a complex, interactive community of microorganisms
- NutriLife®
  - naturally occurring, beneficial soil microbes along with their fermentation liquid medium, and enhanced with humic acid and a 3% analysis of urea ammonium nitrate

AG ORG, Inc.
2476 Bolsover, #357
Houston, TX 77005
http://www.ag-org.com
http://www.ag-org.com/cityfarmer.html
888-246-7416
713-523-4396
713-523-2124 (Fax)
E-mail: mreiner@ag-org.com

Product Categories: Composts/Manures/Guano/Blended Fertilizers, Microbial Inoculants, Micronutrients

- Agricultural Organic Poultry Litter

Arbico Organics
P.O. Box 8910
Tucson, AZ 85738-0910
E-mail: info@arbico.com
http://store.arbico-organics.com/aboutarbico.html
800-827-2847
520-825-9785
520-825-2038 (Fax)

Product Categories: Fertilizers, Soil Amendments, Weed and Insect Control

- Root Maximizer Beneficial Fungi
- PENAC-P Soil Conditioning
  - activates the soil, increases root growth, enhances plant growth, and amplifies natural immunity systems against pests and fungi
- ARBICO's Catalytic Enzymes
- Earthworms
- Organi-Gro Earthworm Castings
- Maxicrop Kelp Seaweed—Liquid and Powder

- Kelp Meal
- Natures Humic Acid
- Nitron Formula A-35 Organic Soil Conditioner
- EM-1 Microbial Inoculant

Back to Nature, Inc. 888-282-2000
P.O. Box 190 806-745-1170 (Fax)
5407 Slaton Hwy.
Slaton, TX 79364

Product Categories: Composted Cotton Burrs, Cattle and Chicken Manures, Blend of Compost, Alfalfa and Humate

Enviro-Guard—AGGRAND Organic Fertilizer 877-689-4719
12151 Vergennes St.
Lowell, MI 49331
E-mail: aggrand-info@guarding-our-earth.com
http://bestsyntheticoil.com/aggrand2/organic-gardening-fertilizer.php

Product Categories:
- 4-3-3 Liquid Natural Organic Fertilizer
  - natural sulfate of potash, bloodmeal, molasses, synergistic compounds, humus extract, and vitamins
- 0-0-8 Liquid Natural Kelp and Sulfate of Potash
- 0-12-0 Liquid Natural Organic Bonemeal
- Liquid Natural Organic Lime

Garden-Ville 210-657-6115
7561 E Evans Road 210-657-9231 (Fax)
14040 Nacogdoches #314 E-mail: richard@garden-ville.com
San Antonio, TX 78266 http://www.garden-ville.com
http://www.garden-ville.com/4376810_36600.htm (supplier list)

Product Categories: Compost Inoculants and Bioactivators, Composts/Manures/Guano/Blended Fertilizers, Humates/Humic Acids, Marine Products, Microbial Inoculants, Micronutrients, Rock Minerals—Phosphates
- Bat Guano
- Garrett Juice
- Liquid Seaweed
- Premium Lawn Fertilizer 7-2-2
  - houactinate, bat guano, urea, feather meal, K-mag, molasses, humate, and other natural ingredients
- Sea Tea 2-3-2
  - fish emulsion, seaweed, molasses, and humate
- Soil Food 9-1-1

    - compost, humate, bat guano, cottonseed meal, fish meal, molasses, brewer's yeast, feed grade urea, and other natural ingredients
- Soil Food Select 6-2-2
    - slow release fertilizer containing bat guano, molasses, compost, and other natural ingredients
- Green Sand
    - non-burning iron source
- Lava Sand
- Liquid Molasses
- Volcanite
    - a proprietary blend of five different crushed volcanic rocks that add minerals and energy to the soil
- Worm Castings

Garlic King
3194 FM 1694
Robstown, TX 78380
361-387-1357
361-387-0179 (Fax)
E-mail: sales@garlicking.com

Product Categories: Marine Products, Micronutrients

GreenSense Fertilizers
1651 Wall Street
Garland, TX 75041
http://www.beorganic.com
972-864-1934
972-864-0128 (Fax)
E-mail: greense@greensense.net

Product Categories: Animal Byproducts, Composts/Manures/Guano/Blended Fertilizers, Humates/Humic Acids, Marine Products, Mycorrhizal Inoculants, Plant Byproducts, Rock Minerals—Phosphates, Worms for Vermicompost

- Lawn and Garden Fertilizer 6-2-4
    - dried poultry litter, feather meal, potash of chloride, dry molasses, animal fat, and zeolites
- Bloodmeal
- Cottonseed Meal
- Worm Castings
- Feather Meal
- GreenSense Blackstrap Molasses
- Menefee Humate
- Lava Sand
- Microboost
    - wheat bran, corn meal, and dry molasses
- Minerals Plus
    - lava sand, Texas greensand, zeolite, sulfur, potassium, iron, and magnesium
- Soft Phosphate with Colloidal Clay (Rock Phosphate)
- Potassium Bicarbonate
- Greenmate
    - dry humate in water soluble form
- Sul-Po-Mag

    - a naturally occurring mineral containing significant quantities of sulfur, potash, and magnesium
- Texas Greensand
- Solid Water
- Mycor Root Builder

J-V Dirt + Loam
3600 FM 973 North
Austin, TX 78725
www.jvdirt.com
512-927-1977
512-927-1014 (Fax)
E-mail: info@jvdirt.com

Product Categories: Landscape Soils, Turkey Compost, Cow Manure Compost

Living Earth Technology Co.
16717 Katy Freeway
Houston, TX 77094
http://www.livingearth.net/home/home.html
281-579-1472
281-579-8801 (Fax)

Product Categories: Mushroom Compost, Compost, Organic Compost, Rice Hull Compost, Top Soil, Mixed Soil Compost, Pecan Shell Mulch, Various Wood Mulches, Aged Soil Conditioner, Lava Sand, Expanded Shale, Texas Greensand

Louisiana Soil Products
5555 McDonald
P.O. Box 1718
Ruston, LA 71273-1718
http://www.louisianasoil.com/index.html
318-251-0228
318-251-0258 (Fax)
E-mail: awalker@louisianasoil.com

Product Categories: Composts, Landscape Soil Mixes, Mulches

Maestro-Gro
P.O. Box 427
Hamilton, TX 76531
254-796-4001
E-mail: maestro@eaze.net

Product Categories: Composts/Manures/Guano/Blended Fertilizers, Microbial Inoculants, Micronutrients

Marshall Grain
2224 East Lancaster
Fort Worth, TX 76103
http://www.marshallgrain.com/marshall/default.asp?s_id=0&
800-361-1286
E-mail: mgc@marshallgrain.com

Product Categories: Beneficial Insects, Bio-inoculants, Compost, Liquid Fertilizers, Dry Fertilizer, Fungicides, Herbicides, Soil Additives, Molasses, Mulches, Soil Amendments
- Bio-inoculants
    - Agrispon®

    - organic soil treatment
  - Agrispon® Bio Inoculant
    - assortment of naturally occurring beneficial organisms
  - Agrispon® Bio Inoculant + Humus
  - Alliance Horticulture Corn Meal
    - all natural fungicide
  - Nature's Guide® Horticultural Corn Meal
  - Medina Soil Activator
- Soil Amendments
  - Rabbit Hill Farm Expanded Shale
  - Rabbit Hill Farm Earthworm Castings
  - Enviro RainDrops
  - Nature's Guide® Dry Humate
  - Black Kow® Organic Peat
  - Alliance Soil Amendment Combination
    - corn meal, wheat bran, and molasses
  - Rabbit Hill Farm Decomposed Granite Sand
  - Rabbit Hill Farm Lava Sand
  - Sunshine Canadian Peat Moss
  - Zeolite
- Soil Additives
  - Copperas Iron Sulfate
  - Hi-Yield® Copperas Iron Sulfate
  - Dr. Iron®
  - EpsoGrow® Plant Food Supplement
  - Epsom Salt
  - Greenlight Iron and Soil Acidifier
  - Rabbit Hill Farm Texas Greensand
  - Calcium Carbonate
  - Gypsum
  - Texas Lime Hydrated Lime
  - Dolomitic Limestone Pellets
  - Hi-Yield® Hydrated Lime
  - Wettable Sulfur
  - Bonide Liquid Sulfur
- Mulches
  - Living Earth Bark Mulch
    - cypress and pine mulches
  - Nature's Guide® Mulches
    - cedar, hardwood, and pecan
  - Cedar Connection Cedar Crystals
    - crystallized cedar mulch
  - Cottonseed Hulls

Medina Agriculture Products
P.O. Box 309
Hondo, TX 78861
http://www.medinaag.com

717-426-3011
830-426-2288 (Fax)
E-mail: feedback@medina.com

Product Categories: Microbial Inoculants

- Medina Soil Activator
  - biological soil activator; loosens and balances soil; stimulates, strengthens, and multiplies soil's indigenous microbes and bacteria
- Medina Plus
  - Medina soil activator plus—micronutrients—magnesium, iron, zinc, parap-aminobenzoic (PABA) acid, riboflavin, thiamin, biotin, nicotinic acid, essential trace elements, and growth hormone from seaweed (cytokinin)
- HuMate Humic Acid
  - liquid humus
- HastaGro Plant Food 6-12-6
  - N-P-K plus Medina soil activator, HuMate humic acid, and nitrogen from urea sources
- Medina Micronutrients
  - high cation exchange capacity
  - micronutrients—iron, zinc, and sulfur
- Medina Granular Organic Fertilizer
  - kelp meal, humate, pasteurized poultry manure, molasses, and greensand
- Beneficial Microbes

Micro-Organics International Division of Houston Tropicare, Inc.
P.O. Box 2505
Spring, TX 77383-2505
E-mail: mkaffel@swbell.net
http://www.microorganics.com

281-363-3330
281-367-1166
281-367-8922 (Fax)

Product Categories: Compost Inoculants and Bioactivators, Marine Products, Microbial Inoculants, Micronutrients

Natural Gardener
8648 Old Bee Cave Road
Austin, TX 78735
http://www.naturalgardeneraustin.com/index.html

512-288-6113
512-288-6114 (Fax)

Product Categories: Compost, Landscape Soils, Mulches

Natural Industries, Inc.
P.O. Box 692075-219
6223 Theall
Houston, TX 77066
http://www.naturalindustries.com

888-261-4731
281-580-1643
281-440-9206 (Fax)
E-mail: billk@naturalindustries.com

Product Categories: Composts/Manures/Guano/Blended Fertilizers

Nature's Way Resources
101 Sherbrook Circle
Conroe, TX 77385
http://www.natureswayresources.com/index.htm
936-321-6990 (Houston Metro)
936-273-1200 (Conroe/Montgomery County)
936-273-1655 (Fax)

Product Categories: Compost, Mulches, Soil Mixtures, Greensand, Granite Sand

NOVUS Wood Group, LP
5900 Haynesworth Lane
Houston, TX 77034
http://www.novuswoodgroup.com/
281-922-1000
281-922-1474 (Fax)
E-mail: info@novussystems.com

Product Categories: Bark Products, Compost, Native Mulch, Colored Mulch, Soil, Soil Amendments

Organics by Gosh
2115 Barton Hills Dr.
Austin, TX 78704
E-mail: info@organicsbygosh.com
http://www.organicsbygosh.com/index.html
512-276-1211
512-440-8264 (Fax)
512-908-7284 (Voice Mail Pager)

Product Categories: All Natural Compost and Fertilizers

Plant Health Care, Inc.
440 William Pitt Way
Pittsburgh, PA 15238
800-421-9051
E-mail: info@planthealthcare.com
http://www.planthealthcare.com/pdfs/useguide.pdf

Product Categories: Mycorrhizal Fungi, Biostimulants, Beneficial Bacteria

- Mycor Tree Saver
  - endo- and ecto-mycorrhizal fungi, biostimulants, soil conditioners, and Terra-Sorb hydrogels
- Healthy Start 12-8-8
  - slow-release biofertilizer tablets with beneficial bacteria and soil conditioners
- MycorTree Injectable with BioPak
  - endo- and ecto-mycorrhizal fungi with beneficial bacteria and biostimulant
- Yuccah
  - yucca schidigera extract
- BioPak
  - organic biocatalyst with beneficial bacteria
- BioPak Plus
  - organic biocatalyst with beneficial bacteria with chelated micronutrients
- Mycor Root Saver
  - endo- and ecto-mycorrhizal fungi with beneficial bacteria, biostimulants, soil conditioners, organic nutrients, and Terra-Sorb

- TerraPam
  - polyacrylamide tackifier
- BioPam
  - polyacrylamide with beneficial bacteria

Progasa
1304 Lucksinger Street
Mission, TX 78572-4530
E-mail: montgie@progasa.com.mx

956-585-0562
956-867-6375
956-584-6915 (Fax)
http://www.progasa.com.mx/

Product Categories: Composts/Manures/Guano/Blended Fertilizers
- MEYFER
  - poultry product with micro- and macronutrients

Rabbit Hill Farm
288 SW CR 0020
Corsicana, TX 75110

903-872-4289
E-mail: rhf@airmail.net

Product Categories: Organic Fertilizers, Landscape Soil Mixes, Sands
- Texas Greensand
- Decomposed Granite Sand
- Lava Sand
- Expanded Shale
- Earthworm Castings
- Zeolite
- Colloidal Clay Phosphate
- Kelp Meal (2-0-5)
- Minerals Plus

Rohde's Nursery & Nature Store
1651 Wall St.
Garland, TX

972-864-1934
www.beorganic.com

Product Categories: Beneficial Insects, Microorganisms, Bacteria, GreenSense Products, Medina Products
- Actinovate
- GreenSense Blackstrap Molasses (Liquid)
- GreenSense Blood Meal
- GreenSense Citrus Oil
- GreenSense Compost
- GreenSense Cotton Seed Meal
- GreenSense Diatomaceous Earth
- GreenSense Earthworm Castings
- GreenSense Epsom Salts
- GreenSense Feather Meal
- GreenSense Fish and Kelp Blend

- GreenSense Fish Solubles
- GreenSense Foliar Juice
- GreenSense Kelp Liquid
- GreenSense Menefee Humate
- GreenSense Mycor Root Builder,
- GreenSense Rock Phosphate
- GreenSense Sul-Po-Mag
- Kaolin
  - kaolinite is a clay mineral with the chemical composition $Al_2Si_2O_5(OH)_4$
- Perma Guard
  - diatomaceous earth
- Solid Water
  - macromolecular polymer extracted from animals and plants

San Jacinto Environmental Supplies 713-957-0707
2221-A W 34th Street 713-957-0707 (Fax)
Houston, TX 77018
http://www.sanjacorganic.com/

Product Categories: Composts/Manures/Guano/Blended Fertilizers, Cover Crop Seeds, Humates/Humic Acids, Marine Products, Microbial Inoculants, Micronutrients, Mycorrhizal Inoculants, Plant Byproducts, Rock Minerals—Non-phosphates, Rock Minerals—Phosphates

- Granular Organic Fertilizers
  - Microlife (6-2-4)
    - a superior, long lasting, all organic, biological fertilizer that promotes sound plant and soil health; granulated, homogenized with 2% Fe, 70 trace minerals, enzymes, and beneficial microorganisms, including endo- and ecto-mycorrhizal
  - Microlife "Ultimate" (8-4-6)
    - humates, rock minerals, special bio-inoculates, including endo- and ecto-mycorrhizal and biostimulants
  - Microlife "Ultimate" (8-0-6)
    - 100% slow release nutritional compound of microlife plus the right amounts of humate, rock minerals, special bio-inoculates, including endo- and ecto-mycorrhizal and biostimulants with zero phosphate
  - Fish Meal
    - very concentrated source of nitrogen, amino acids, fatty acids, vitamins, and trace minerals
  - Alfalfa Meal
    - nitrogen, phosphate, potash, calcium, magnesium, valuable trace elements, vitamin A, vitamin B complex, IBA growth stimulator, and folic acid, plus sugar, starches, proteins, fiber, co-enzymes, and amino acids
  - Soft Rock Phosphate
    - provides immediate and long-term source of phosphate
  - Kelp Meal 1-0-3
    - 70 trace minerals, amino acids, growth stimulants, carbohydrates, and vitamins
  - Cottonseed Meal 7-2-2

        - nitrogen and has an acid pH; naturally slow releasing (3–6 months); lots of trace minerals
    - Molasses
        - molasses is sugar, sugar is carbon, and carbon is the building block of all life; soil microbes love molasses, and a healthy population of soil microbes will improve all soils and plants; also contains potassium, sulfur, iron, magnesium, and B vitamins
    - Sulfate of Potash Magnesia 0-0-22 (22% S, 18% Mg) "K-Mag"
    - Sulfate of Potash 0-0-50 (18% S)
    - Magnesium Sulfate (9.8%, Mg, 6% S) "Epson Salts"
    - Gypsum (23% Ca, 18% S)
    - Humic Acid Complex 15% (Humic Acid 10%, Fulvic Acid 5%)
        - superbly blended humic acid product that naturally contains fulvic acid, surfactants, wetting agents, and plant hormones that open up the leaf stomatas, thus allowing more efficient penetration and translocation of herbicides
- Organic Inoculants and Biostimulants
    - PGA Plus
        - 47 strains of positive soil microorganisms, enzymes, and catalytic agents
    - MicroGro Granular
        - 47 strains of beneficial bacteria and fungi including streptomyces, trichoderma, pseudomonas , gliocladium, and a extensive variety of bacillus all mixed with a biostimulant package
    - Rozanova Mycorrhizal Inoculants
        - billions of active ecto- and endo-mycorrhizal spores mixed together with a biostimulant package consisting of kelp, humates, yucca, amino acids, plant hormones, and natural sugars, as well as beneficial bacteria; in addition, the tree transplant packages also contain water absorbing-releasing polymer
    - Tree Transplant
        - endo/ecto-mycorrhizal inoculant blend, with humic acid, water absorbent polymers, and organic nutrients; a dry mix that is ideal for most transplanting needs
    - Tree Injectables
        - for deep root injection: endo/ecto-mycorrhizal inoculant with soluble humic acid
    - Humates
        - highly charged particles of complex carbon mixed with simple carbon
    - Eco-Min
        - combination of selected granites that provide over 100 minerals with a patented biostimulant attached
    - Ocean Harvest 4-2-3
    - Super Seaweed
        - cold-processed kelp, soluble fish, humic acid, molasses, and selected plant extracts
    - Maximum Blooms 3-8-3
        - N-P-K, natural sugars, amino acids, enzymes, plant hormones, vitamins, natural chelators, and plant stimulator
    - Molasses
- Organic Soil Amendments
    - Corn Meal
    - Leaf Mold Compost

        - Sulfur (90% S) Mini-Prilled
        - Liquid Sulfur
        - Mini Granular Sulfur
        - Microlife Biological Organic Fertilizer (6-2-4)
        - Eco-Min Rock Minerals and Biostimulant
            - combination of three selected granites that provide over 100 minerals, a patented biostimulant with sugars, live yeast, organic compounds, and a paramagnetic energy value of over 3000
        - Dolomite Lime (24% Ca, 10% Mg)
        - Granulated Humates
    - High Calcium Limestone (35% Ca)

Soil Building Systems 866-SOIL-SBS
1770 "Y" Street 972-831-8181
Dallas, TX 75229 972-831-8080 (Fax)
http://www.soilbuildingsystems.com/ProductList.php

Product Categories: Compost, Mulch, Soils, Sand, Rock, Dirt/Clay

Spray-N-Grow 800-288-6505
P.O. Box 2137 361-790-9033
Rockport, TX 78382 361-790-9313 (Fax)
E-mail: jnatalie@spray-n-grow.com http://www.spray-n-grow.com

Product Categories: Microbial Inoculants, Micronutrients

- Coco-Wet
    - all natural wetting agent
- Bill's Perfect Fertilizer
    - 6-11-5
- Triple Action 20
    - concentrated foliar fungicide, bactericide, algaecide
- Spray-N-Grow
    - micronutrient complex

Texas Organic Products (512) 421-1338
Texas Landfill Management E-mail: top@texasdisposal.com
Texas Disposal Systems
12200 Carl Road
Austin, TX 78747
http://www.texasdisposal.com

Product Categories: Compost, Mulch, Topsoil

Texas Power Mulch 713-895-9044
P.O. Box 1565 281-304-6291 (Fax)
Cypress, TX 77410-1565

http://www.texaspowermulch.com/products.html

- Hardwood Mulch
- Native Mulch
- Compost
- Enriched Topsoil
- Landscape Mix
- Filtrexx Filter Socks

Triganic Organic Minerals
519 Estelle Drive
Rockdale, TX 76567
512-446-3244
E-mail: lmcguire@classicnet.net
http://www.triganic.com

Product Categories: Compost Inoculants and Bioactivators, Composts/Manures/Guano/Blended Fertilizers, Humates/Humic Acids, Hydroponic Fertilizer, Micronutrients, Rock Minerals—Non-phosphates, Rock Minerals—Phosphates

- Triorganic Supreme
  - montmorillonite, humate, and diatomaceous earth, along with other organic minerals, provides a slow release of silicon, humate, and more than 72 rare earth minerals; blend with rooting media, top dress around plant stem, or add directly to nutrient solutions
- Montmorillonite
- Humate (70% Greens Grade)

Vital Earth Resources
P.O. Box 1148
Gladewater, TX 75647
http://www.vitazyme.com
800-245-7645
903-845-2163
E-mail: daniel@vitalearth.com

Product Categories: Composts/Manures/Guano/Blended Fertilizers

- Composted Peat Replacer
  - hardwood sawdust, poultry litter, grain byproducts, and mineral supplement
- Composted Cotton Burrs

Whittlesey Landscape Supplies
3219 South IH-35
Round Rock, TX 78664
http://www.989rock.com/index.html
512-989-ROCK (7625)
512-491-7195 (Fax)

Product Categories:

- Austin Soil Amendment Made Specifically for the Central Texas Area
  - blend of sands and compost to break down clay content, 66.66% organic matter
- Professional Mix
  - 50% organic matter, 20% mineral sands
- Garden Mix for Annual Flowers, Shrubs, and Native Perennials
  - 33% organic matter, 22% sands
- Landscape Mix (22% organic matter, 22% sands)

- Dillo Mix
    - 50% organic matter
- Pro-Gro™
    - 100% organic potting soil
- Screened Chocolate Loam
- Dillo Dirt, the City of Austin's Own Recycled Fertilizer

APPENDIX D:
DETAILS FOR MACRO- AND MICRONUTRIENTS

This appendix is adapted from the Atlantic Canadian Organic Regional Network's *Crop Production, Fertilizer, Plant Food and Soil Amendments* (1).

MACRONUTRIENTS

Nine major elements essential for healthy growth found in larger quantities than the eight micronutrients

Calcium

- important component of cell walls, cell division, and nutrient uptake
- participates in the maintenance of membrane permeability and structure
- activates some enzymes
- addition will raise soil pH
- loosens soil
- symptoms of calcium deficiency
  - includes tip dieback of buds and new leaves
- sources
  - calcitic lime
  - calphos (calcium phosphate)
  - crustacean shell powder
  - gypsum
  - bone meal

Carbon

- major component of organic molecules
- plants grown outdoors will not be deficient in carbon

Hydrogen

- major component of organic molecules
- if watered, a plant will not suffer hydrogen deficiency

Magnesium

- activates enzymes that form oils, starch, and fats
- component of the chlorophyll molecule
- sources
  - dolomite lime
  - biotite
  - Epsom salts
  - kieserite
  - langbeinite (Sul-Po-Mag)
- symptoms of magnesium deficiency
  - older growth—interveinal chlorosis
  - new growth—reduced or stunted

Nitrogen

- building block of amino acids, proteins, and nucleic acids (genetic material), chlorophyll, and enzymes
- only available to plants when fixed by soil microorganisms (nitrogen fixing)
- sources
  - legumes
  - compost
  - seed meals
  - blood meal
- symptoms of nitrogen deficiency
  - chlorosis and stunted growth

Oxygen

- major component of organic molecules
- plants "breathe" carbon dioxide (CO_2)
  - respiration breaks CO_2 into carbon and oxygen for use
- plants uptake through roots also

Phosphorous

- component of
  - nucleic acid (genetic material)
  - ADP and ATP (which are vehicles of energy transfer in and amongst cells)
  - several coenzymes (which activate biochemical processes)
- root development, and flower and fruit formation
- at low pH (< 5.5) becomes fixed to aluminum and iron in soil
- sources
  - poultry manure compost (sometimes phosphorus rich)
  - lime
  - bone meal
  - blood meal
  - mineral phosphates
  - colloidal phosphate
- symptoms of phosphorus deficiency
  - difficult to identify—reddening or general darkening of the foliage

Potassium

- protein synthesis
- operation of the stomata (opening responsible for plant respiration)
- aids in disease resistance
- seed and root development
- sources
  - greensand
  - granite dust/meal
  - kelp meal
  - wood ash
  - fish meals/emulsion

    - langbeinite (Sul-Po-Mag)
- symptoms of potassium deficiency
    - overall weakness, especially in its stem, yellow leaf margin

Sulfur
- component of some amino acids, proteins, and chlorophyll
- important for N-fixing microorganisms
- can be a sign of symptoms of sulfur deficiency
    - pale or yellowish, weak young leaves
    - stunted growth or delayed ripening
- fungicide and mites and chiggers control
    - can be harmful to beneficial insects and microorganisms

MICRONUTRIENTS

Eight nutrients essential to plant growth and health present in very small but essential quantities

Boron
- carbohydrate transport in plants
- seed development
- pH above 6.5 reduces availability
- metabolic regulation
- symptoms of boron deficiency
    - bud dieback

Chlorine
- necessary for osmosis and ionic balance
- photosynthesis

Cobalt
- catalyst in nitrogen fixation

Copper
- component of some enzymes and vitamin A
- fungicide
- levels can build up in soil with use
- can become toxic
- symptoms of copper deficiency
    - browning of leaf tips and chlorosis (usually newer growth turns yellow and older growth- areas between the veins yellow first)

Iron
- essential for chlorophyll synthesis
- symptom of iron deficiency
    - chlorosis

Manganese

- activates some important enzymes involved in chlorophyll formation
- important cation in soil
- role in carbohydrate and nitrogen metabolism
- sources
  - kelp extract
- symptoms of manganese deficiency
  - chlorosis between the veins of its leaves
- manganese availability partially dependent on soil pH

Molybdenum

- reduces nitrates into usable forms
- used for nitrogen fixation
- necessary for amino acids and protein formation
- may be deficient in sandy, compacted, low phosphorus soils

Zinc

- participates in chlorophyll formation
- activates many enzymes
- may be deficient in high phosphorus, high pH, low organic matter soils (subsoils)
- symptoms of zinc deficiency
  - chlorosis and stunted growth

APPENDIX D REFERENCES

1. Atlantic Canadian Organic Regional Network. "Crop Production, Fertilizer, Plant Food and Soil Amendments." Published online at http://www.acornorganic.org/cgi-bin/organopedia/itemdisplay?5, accessed June 2006.

APPENDIX E:
ORGANIC AMENDMENT MATRIX

Organic Soil Additives and Amendments with Associated Performance Characteristics

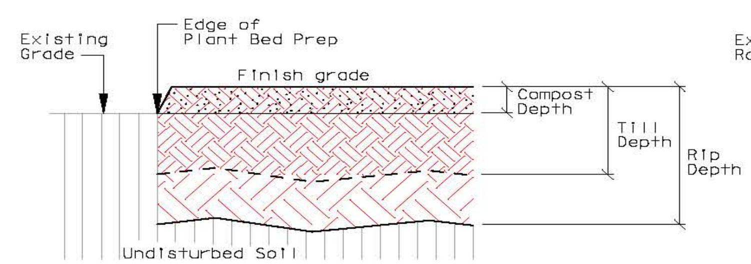
	Erosion Control	Improved Soil Structure	Moisture Retention	Aeration Reduced Compaction	Surfactant	Microorganism	Microbe Stimulator	Decompose OM Aid	pH Modifier	Enhance CEC	Slow Release >12 Mo.	Med. Release 4-12 Mo.	Quick Release < 4 Mo.	Increase Root Surface	Plant Hormone	Root Growth	Nutrient Uptake Aid	Suppress Disease/Insect	Weed Control	Reduce Soil Toxins	Nitrogen Fixing	Nitrogen Source	Phosphorus Source	Potassium Source	Trace Elements	Other Nutrients	Trace Minerals
Alfalfa Meal/Pellets							X															X	X	X			
Blood Meal													X		X							X					
Bone Meal												X										X	X	X			
Calcitic Lime																										Ca	
Composts	X	X	X	X						X												X					
Corn Meal/Gluten							X												X			X	X	X			
Cottonseed Meal									--																X		
Dolomite Lime									+																	Ca, Mg	
Epsom Salts/Kieserite																										Su, Mg	
Feather Meal		X						X														X					
Fish Emulsion—Liquid																						X	X	X			
Fish Meal—Dry																						X	X	X			
Greensand				X					+		X													K_2O	X	silica	X
Granite Rock Dust/Meal											X													X	X	silica	X
Guano							X				X							X				X	X	X	X		
Gypsum			X	X													X										
Humate							X																				
Humus		X	X	X			X	X	X	X							X			X							
Humic Acid							X										X	X									
Langbeinite/Sul-Po-Mag/K-Mag													x											x	X	Su, Mg	
Lava Rock & Sand				X			X																		X		
Molasses							X						X											X	X	S	
Mycorrhiza				X		X								X		X	X	X									
Microorganisms																											
Peat			X	X					--																		
Polymers																											
Rock Phosphate																X							X			Ca	
Sea Kelp/Cytokinin		X													X							X	X	X	X		
Sulfur									--				X														
Soybean Meal																											
Wood Ash											X													X	X	Ca	
Worm Castings			X	X			X										X	X				X	X	X		Ca	
Zeolites											X													X			

APPENDIX F:
HOUSTON DISTRICT BED PREPARATION PLAN SHEETS AND SPECIFICATIONS

TYPE OF WORK				ITEMS AND REQUIREMENTS FOR EACH TYPE OF WORK		
192-2063 PLANT BED PREP (TYPE I) SY	192-2064 PLANT BED PREP (TYPE II) SY	192-2065 PLANT BED PREP (TYPE III) SY	192-2066 PLANT BED PREP (TYPE IV) SY	**Reference Item 161, 192 of the Texas Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges 2004 for specifications, dimensions, volumes and measurements that are not shown. Reference Special Specification Item 1009.**		
✓	✓	✓	✓	161-2012 GENERAL USE COMPOST CY	APPLICATION RATE Item 161.2.C. General Use Compost. Apply 2 in. uniform layer over bed preparation area.	Item 161.2. Materials. Compost producer's STA certification must be dated to meet STA requirements (certification must be within 30 or 90 days). Lab analysis performed by an STA-certified lab must be dated within 30 days before delivery of the compost.
✓	✓	✓	✓	1009-2002 LANDSCAPE SOIL AMENDMENT (TYPE I) SY	APPLICATION RATE 0.30 lbs/SY	Use a non-chemical fertilizer which: (1) Is registered with Texas State Chemist as a commercial fertilizer. (2) Meets USEPA guidelines for unrestricted use. (3) Derived from the following biological sources: Dehydrated Alfalfa Meal, Dehydrated Fish Meal, Dicalium Phosphate, Soft Rock Phosphate, Dehydrated Kelp Meal, Hydrolyzed Feather Meal, Bat Guano, Sulfur, Potassium Sulfate, and Potassium Sulfate of Magnesia. (4) Includes the following BIO Inoculates; (4) Bacillus, (3) Pseuomonas, Streptomyces, Mycorrhizal Fungi, (2) Arthrobacter, (2) Azotobacter, (2) Asperigillus and (2) Trichoderma. The Bacillus, Pseuomonas, Streptomyces, Mycorrhzal Fungi, and Trichoderma must have a combined total count of $1x10^{9}$ of Colony Forming Units (CFU) per gram of fertilizer (Independent certified lab analysis required). (5) Has an average Humic Acid of 3.68(+/- 0.1)%, Ulmic Acid of 1.12(+/- 0.1)%, and Fulvic Acid of 1.09(+/- 0.1)% (Independent certified lab analysis required). Use the following product or an approved equal: MicroLife Ultimate 8-4-6, San Jacinto Environmental Supplies, 713-957-0909.
✓	✓	✓	✓	1009-2003 LANDSCAPE SOIL AMENDMENT (TYPE II) SY	APPLICATION RATE For Plant Bed Preparation Areas: Type I, Type II, Type III = 0.125 lbs/SY Type IV = 0.25 lbs/SY	Humate containing 1.5% sulfur and 2.25% iron in the raw material and greater than 45% humic acid, dextrose 2.5% to 5% on weight basis. Pelletized humate without added binders and pass #16 mesh. Use the following product or an approved equal: San Jacinto Humate, San Jacinto Environmental Supplies, 713-957-0909.
✓	✓	✓	✓	1009-2004 LANDSCAPE SOIL AMENDMENT (TYPE III) SY	See PLANTING AND ESTABLISHMENT SHEET 6 of 8 For Requirements	
				1009-2005 LANDSCAPE SOIL AMENDMENT (TYPE IV) SY	See PLANTING AND ESTABLISHMENT SHEET 6 of 8 For Requirements	
				1009-2006 LANDSCAPE SOIL AMENDMENT (TYPE V) SY	See PLANTING AND ESTABLISHMENT SHEET 6 of 8 For Requirements	
✓				RIPPING/TRENCHING Incidental to Item 192 Plant Bed Preparation.	RIP/TRENCH DEPTH Rip/Trench to a depth of 18 inches (+/- 2"). Distance between each rip/trench is 24 inches.	
✓	✓	✓		ROTOR TILLING Incidental to Item 192 Plant Bed Preparation.	ROTOR TILL DEPTH After application of compost and amendments and rip/trench (when required), rotor till to a depth of 8 inches (+/- 2").	
		✓	✓	HERBICIDE and MOWING Incidental to Item 192 Plant Bed Preparation. Scalp mow 15 days after final herbicide treatment.	APPLICATION RATE Prior to all other work, apply two applications of an approved herbicide with 15 days between the applications. Apply herbicide during weather conditions and at a rate per manufacturer's recommendations.	

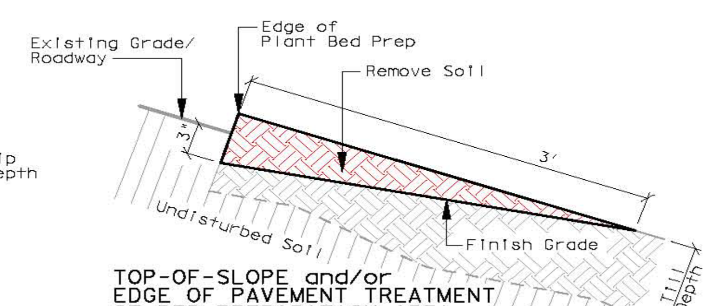
GENERAL BED PREPARATION NOTES:

1. Reference Item 192 of the Texas Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges 2004 for specifications, dimensions, volumns and measurements not shown.
2. Locate and stake all underground conduits and utilities associated with but not limited to: CTMS, CTMS power supply, lighting, signal wires and detectors, gas, electric, telephone, fiber optics, etc.
3. Locate and stake existing ground boxes, inlets, culverts, manholes, etc. within the project area with a 4' wooden stake painted orange. Maintain the stakes in place for duration of the project. Remove stakes when directed by engineer.
4. Repair any damage within right of way caused by contractor at no additional expense to the Department.
5. Provide a 1000 SF "mock up" of soil amendment, general use compost, and bed preparation complete and in place within an approved area for approval by engineer.
6. Pick-up litter prior to scalp mow and bed preparation.
7. All concrete, steel, trash, and other debris uncovered during bed preparation work which the engineer determines as detrimental to the project will become the responsibility of the contractor and disposed of in an approved manner. Debris removal will occur daily and will be incidental to bed preparation and will not be paid for separately.



PLANTING BED PREPARATION SECTION

SEE ITEMS AND REQUIREMENTS THIS SHEET FOR DIMENSIONS, RATES, AND SPECIFICATIONS
(See Top-of-Slope detail this sheet when applicable)



TOP-OF-SLOPE and/or EDGE OF PAVEMENT TREATMENT OF BED PREPARATION AREA

Install at all areas with the following conditions:
Within the bed preparation areas at top-of-slope (adjacent to shoulder sections and areas with slotted barrier/curb) and/or at edge of roadway, remove tilled or untilled (TYPE IV) soil as shown. Evenly distribute removed soil in a thin layer over adjacent existing tilled or untilled (TYPE IV) soil being careful not to create a mound. This work is incidental to Item 192 Plant Bed Prep Preparation.

Texas Department of Transportation

HOUSTON DISTRICT

PLANTING AND ESTABLISHMENT

SHEET 5 of 8

Details not to scale

BED PREPARATION

FILE:	FED DIV	STATE	PROJECT NUMBER			SHEET
	6	TEXAS				
ORIGINAL:	DIST	COUNTY	CONTROL	SECT	JOB	HIGHWAY
	12	HARRIS	3256	02	078, ETC	BW 8

ITEM 1009-2004 LANDSCAPE SOIL AMENDMENT (TYPE III) and
ITEM 1009-2005 LANDSCAPE SOIL AMENDMENT (TYPE IV) and
ITEM 1009-2006 LANDSCAPE SOIL AMENDMENT (TYPE V) requirements.

MATERIALS REQUIREMENTS

Compost for use in liquid compost/extract must contain the following (per gram dry weight of compost):
1. Test within range of Soil Food Web standards using a full bio-assay to include the following:
    a) 15-25 micrograms of active bacteria,
    b) 100- 3000 micrograms total bacterial biomass,
    c) 15-25 micrograms active fungal biomass,
    d) 100-300 micrograms total fungal biomass,
    e) 10,000 each of flagellates and amoebae,
    f) 20-100 ciliates, and
    g) 20 to 30 beneficial nematodes.
2. Meet the Solvita Compost Maturity test of 8.0 or higher.

Liquid compost/extract must contain the following (per gram dry weight):
1. 150-3000 micrograms total bacterial biomass,
2. 2-20 micrograms total fungal biomass,
3. 1000 each of flagellates and amoebae,
4. 20-50 ciliates, and
5. 2-10 beneficial nematodes.

Liquid compost must be verified, with time and date, for content to have minimum activity and meet minimum standards as specified above using a 10x and 40x microscope with camera attachment by a Soil Foodweb Certified Advisor or their representative. This verification must be within 30 minutes of material leaving premises on the day of manufacture. Picture will be kept on file for each 500 gallons manufactured.

Liquid compost/extract additives include the following:
1. Mycorrhizal fungi endo/ecto blend sourced with a minimum potency of 100,000 propagules per pound with NO Tricoderma included in the innoculum.
2. Humate, low sodium, naturally processed 70% humate that has been liquefied to 12% humic-fulvic as available from Mesa Verde Resources at 877-418-8776 or approved equal.
3. Fulvic acid derived from natural shale ore as available from Sustainable Growth Texas at 936-232-5738 or approved equal.
4. Soluable kelp seaweed, dehydrated liquid extract made from the seaplant Ascophyllum nodosom as available from Sustainable Growth Texas at 936-232-5738.
5. Naturally derived blackstrap non-sulfured molasses (for foliar application only).

Liquid compost/extract with additives solution must sit on air for 3-4 hours and monitored every 1/2 hour with a Dissolved Oxygen Meter to assure the material does not drop below 6ppm oxygen content during full activation period.

EQUIPMENT REQUIREMENTS

For each batch use a delivery tank verified for overall cleanliness, to be free of residue, soil, compost or stains. Tank shall then be rinsed with clean non-chlorinated or non-chloramines treated well water before filling with Liquid Compost. All equipment used for application of liquid compost must have never been used or will not be used with any non organic conventional inorganic fertilizers or chemical herbicides or pesticides, owner must submit written verification to this nature.

Tank shall be equipped with two, 2 inch quick coupler type fittings capable of coupling, without leaks. All lines and fittings should have quick couplers at every junction. Ninety (90) degree bend fittings should be avoided for quick clean out and verification of cleanliness.

Delivery tank must be equipped with an operating circulation pump of a low velocity, high volume pump of diaphragm or centrifugal design.

Injectors capable of penetrating four (4) inches into soil and/or root balls as manufactured by LESCO Deeproot Feeder at 713-466-6730 or approved equal.

Delivery tank must be equipped with an operating aeration system of a ceramic type diffuser and air pump of dry design

Diffused oxygen meter.

TRANSPORT, STORAGE AND APPLICATION REQUIREMENTS

Liquid compost/extract with additives solution must be circulated for five (5) minutes per five hundred (500) gallons of material every three (3) hours. Liquid compost/extract with additives solution must be continuously aerated from time of manufacture through complete application. All solution must be applied within 24 hours, or new material must be sourced. Materials not applied within 24 hours is not allowed.

CONSTRUCTION METHODS AND APPLICATION RATES

1009-2004 LANDSCAPE SOIL AMENDMENT (TYPE III) SY
Installation: Install prior to final acceptance and prior to beginning Item 192 LANDSCAPE PLANTING MAINTENANCE PERIOD.
Limits: Each injected tree and woody shrub equals one square yard of Landscape Soil Amendment (Type III).
Inject 1/2 gallon liquid compost/extract with additives solution four (4) inches into the root zone and/or rootball of each tree and woody shrub only. Mix additives with liquid compost/extract using the following rates:
1. Mycorrhizal fungi endo/ecto blend: 30 lbs per 500 gallons of liquid compost/extract,
2. Humate: 30 lbs per 500 gallons of liquid compost/extract,
3. Fulvic acid: 32 oz per 500 gallons of liquid compost/extract,
4. Soluable kelp seaweed: 2 lbs per 500 gallons of liquid compost/extract.

1009-2005 LANDSCAPE SOIL AMENDMENT (TYPE IV) SY
Limits: Spray foliar limits equal bed preparation limits of tree and woody shrub areas only. Spray foliar application over all tree and woody shrubs and associated bed preparation areas.
Solution must be sprayed targeting the full surface of the plant including leaves (top and bottom), limbs and trunk.
Spray foliar application of liquid compost/extract with additives at the following rates:
1. Liquid compost/extract: 500 gallons per acre,
2. Humate: 2 lbs per acre,
3. Fulvic acid: 32 oz per acre,
4. Soluable kelp seaweed: 2 lbs per acre,
5. Blackstrap molasses: 16 oz per acre.

1009-2006 LANDSCAPE SOIL AMENDMENT (TYPE V) SY
Limits: Spray foliar limits equal bed preparation limits of ornamental grass and shrub areas only. Spray foliar application over all ornamental grasses and shrubs and associated bed preparation areas.
Solution must be sprayed targeting the full surface of the plant including leaves (top and bottom), and center clump of plant.
Spray foliar application of liquid compost/extract with additives at the following rates:
1. Liquid compost/extract: 500 gallons per acre,
2. Humate: 1 lb per acre,
3. Fulvic acid: 48 oz per acre,
4. Soluable kelp seaweed: 1 lb per acre,
5. Blackstrap molasses: 32 oz per acre.

Soil Foodweb Certified Advisor:
Sustainable Growth Texas
103 Sherbrook Circle
Conroe, TX 77385
936-232-5738
sustainablegrowthtexas.com

Soil Foodweb New York, Inc.
555-7 Hallock Ave.
Port Jefferson Station, NY 11776
631-474-8848
soilfoodwebny.com

Soil Foodweb Oregon, LLC
728 SW Wake Robin Ave.
Corvallis, Oregon 97333-1612
541-752-5066
soilfoodweb.com

Texas Department of Transportation

HOUSTON DISTRICT

PLANTING AND ESTABLISHMENT

SHEET 6 of 8

LIQUID COMPOST/EXTRACT

Details not to scale

FILE:	FED DIV	STATE	PROJECT NUMBER			SHEET
	6	TEXAS				
ORIGINAL:	DIST	COUNTY	CONTROL	SECT	JOB	HIGHWAY
	12	HARRIS	3256	02	078, ETC	BW 8

STD K-4

ITEM 192 LANDSCAPE PLANTING MAINTENANCE REQUIREMENTS

After completion of the project installation, as shown in the plans and approved by the engineer, begin maintenance activities for a period of 365 calendar days as described in Special Provision 192-013.
Payment in accordance with Special Provision 192-013 is subject to completion of all scheduled maintenance activities, timeline may also be suspended for failure to complete scheduled maintenance activities.
All maintenance work is incidental and is not paid for separately unless otherwise shown on plans.
Reference Item 170 and 192 of the Texas Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges 2004 and Special Specification 1009 for specifications, dimensions, volumes and measurements that are not shown.
Notify engineer prior to each site visit, determination of the completeness of work will be done in the presence of the engineer same day as work activity.

TIMELINE (Days): 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 365

DESCRIPTION OF WORK	1 Thru 7	8 Thru 15	16 Thru 22	23 Thru 30	31 Thru 37	38 Thru 45	46 Thru 52	53 Thru 60	61 Thru 67	68 Thru 75	76 Thru 82	83 Thru 90	91 Thru 97	98 Thru 105	106 Thru 112	113 Thru 120	121 Thru 127	128 Thru 135	136 Thru 142	143 Thru 150	151 Thru 157	158 Thru 165	166 Thru 172	173 Thru 180	181 Thru 187	188 Thru 195	196 Thru 202	203 Thru 210	211 Thru 217	218 Thru 225	226 Thru 232	233 Thru 240	241 Thru 247	248 Thru 255	256 Thru 262	263 Thru 270	271 Thru 277	278 Thru 285	286 Thru 292	293 Thru 300	301 Thru 307	308 Thru 315	316 Thru 322	323 Thru 330	331 Thru 338	339 Thru 346	347 Thru 354	355 Thru 365
192.3.0.1. **WATERING** (See PLANTING AND ESTABLISHMENT SHEET 1 of 8, VEGETATIVE WATERING SCHEDULE FOR TREES, SHRUBS, VINES) and/or (See PLANTING AND ESTABLISHMENT SHEET 2 of 8 VEGETATIVE WATERING SCHEDULE FOR PALMS ONLY)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
192.3.0.2. **MOWING, TRIMMING, AND EDGING** (From back of curb, retaining wall, barrier, and riprap to bed preparation areas, otherwise 6' width around outside edge of bed preparation areas, around and between planting bed preparation areas, including areas around any structures within the outer limits adjacent to the roadway) DO NOT MOW, TRIM, OR EDGE WITHIN 3' of ANY TREE	MOW EIGHT TIMES PER 365 DAY PERIOD, ONCE PER MONTH, DURING THE LAST WEEK OF: APRIL, MAY, JUNE, JULY, AUGUST, SEPTEMBER, OCTOBER, NOVEMBER																																															
192.3.0.3. **PLANT BASIN, BED, AND WORKSITE MAINTENANCE** (Includes keeping all inlets within or near the bed preparation areas free of compost. Maintain bed preparation areas as shown below and reshape beds every 30 days or as site conditions and weather require. If no requirement is selected, maintain per Item 192.3.0.3) **WEED CONTROL REQUIREMENT** ☐ Maintain weed-free per Item 192.3.0.3. Cord trimmers are not allowed. Replace damaged plants per Item 192.0.9 ☑ Maintain grasses and weeds at 24" maximum height. Eradicate all vines regardless of height. Eradicate invasive shrubs and trees as directed. Method must be either a spot-treatment chemical application such as a wick applicator or manual hand pulling of weeds and vines. Spray applicators are not allowed. Hand-pull previously treated dead plants over 24" tall.		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
192.3.0.4. **PLANT SUPPORTS** (Remove plant stakes and all appurtenances within last 10 days of this schedule unless this Item 192 maintenance period is followed by Item 193 establishment period, unless otherwise directed by engineer)		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
192.3.0.5. **PRUNING** (Includes palm plant material and dead, diseased, or damaged palm fronds.)		✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓		
192.3.0.6. **INSECT, DESEASE, AND ANIMAL INSPECTION AND TREATMENT** (Exterminate all active ant colonies in bed preparation areas)		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
192.3.0.7. **LITTER AND DEBRIS COLLECTION AND DISPOSAL** (Includes planting bed preparation areas and designated mowing limits. In addition, keep all inlets within or near planting bed preparation areas free of debris and litter)		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
192.3.0.8. **TREE TRUNK WRAP AND PROTECTION GUARD REMOVAL AND DISPOSAL** (Not applicable)																																																
192.3.0.9. **PLANT REPLACEMENT*** (See Special Provision 192-013)				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓
1009-2005 **SOIL AMENDMENT (TYPE IV)** (PLANTING AND ESTABLISHMENT SHEETS 5 AND 6 of 8, each application will be paid for separately)																	✓																															
1009-2006 **SOIL AMENDMENT (TYPE V)** (PLANTING AND ESTABLISHMENT SHEETS 5 AND 6 of 8, each application will be paid for separately)	✓																																												✓			
FERTILIZER (Only when Item 192 Palm Material is part of the contract, see PLANTING AND ESTABLISHMENT SHEET 2 of 8, REQUIREMENTS AFTER PLANTING)																✓																✓																✓
IRRIGATION SYSTEM (Only when Item 170 Irrigation System or a temporary irrigation system is part of the contract, see IRRIGATION DETAILS AND MATERIALS SHEET 1 OF 3, GUARANTEE AND ACCEPTANCE)		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓

* Remove any materials damaged by actions described in Item 7.14.A.
Removal and disposal of damaged materials is incidental to Item 192.
Contracter may be reimbursed for plant replacement in accordance with Item 7.14.A.
Theft is not a reimbursable repair.

✓ = Work required during defined period of timeline.
All work must be completed for entire project.

Texas Department of Transportation

HOUSTON DISTRICT

PLANTING AND ESTABLISHMENT

SHEET 7 of 8

MAINTENANCE

FILE:	FED DIV	STATE	PROJECT NUMBER			SHEET
	6	TEXAS				
ORIGINAL:	DIST	COUNTY	CONTROL	SECT	JOB	HIGHWAY
	12	HARRIS	3256	02	078, ETC	BW 8

STD K-4

ITEM 193 LANDSCAPE ESTABLISHMENT REQUIREMENTS

After completion of the Item 192 maintenance period, as shown in the plans and approved by the engineer, begin Item 193 establishment activities for a period of 12 months.
Reference Item 193 of the Texas Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges 2004 for specifications, dimensions, volumes and measurements that are not shown.
All establishment work is paid for separately in accordance with Item 193 unless otherwise shown on plans.
Notify engineer prior to each site visit, determination of the completeness of work will be done in the presence of the engineer same day as work activity.

DESCRIPTION OF WORK — TIMELINE (Days)

0 30 60 90 120 150 180 210 240 270 300 330 365

DESCRIPTION OF WORK	1 Thru 7	8 Thru 15	16 Thru 22	23 Thru 30	31 Thru 37	38 Thru 45	46 Thru 52	53 Thru 60	61 Thru 67	68 Thru 75	76 Thru 82	83 Thru 90	91 Thru 97	98 Thru 105	106 Thru 112	113 Thru 120	121 Thru 127	128 Thru 135	136 Thru 142	143 Thru 150	151 Thru 157	158 Thru 165	166 Thru 172	173 Thru 180	181 Thru 187	188 Thru 195	196 Thru 202	203 Thru 210	211 Thru 217	218 Thru 225	226 Thru 232	233 Thru 240	241 Thru 247	248 Thru 255	256 Thru 262	263 Thru 270	271 Thru 277	278 Thru 285	286 Thru 292	293 Thru 300	301 Thru 307	308 Thru 315	316 Thru 322	323 Thru 330	331 Thru 338	339 Thru 346	347 Thru 354	355 Thru 365
193.3.A.1. **PRUNING** (Includes palm plant material and dead, diseased, or damaged palm fronds.)				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓
193.3.A.2. **INSECT, DESEASE, AND ANIMAL CONTROL** (Exterminate all active ant colonies in bed preparation areas)		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
193.3.A.3. **FERTILIZATION** (Only when Item 192 Palm Material is part of the contract, see PLANTING AND ESTABLISHMENT SHEET 2 of 8, REQUIREMENTS AFTER PLANTING)																✓																✓																✓
193.3.A.4. **MULCHING, PLANT BASIN, AND PLANT BED MAINTENANCE** (Includes keeping all inlets within or near the bed preparation areas free of compost. Maintain bed preparation areas as shown below and reshape beds every 30 days or as site conditions and weather require. If no requirement is selected below, maintain per Item 193.3.A.4) **WEED CONTROL REQUIREMENT** ☐ Maintain weed-free per Item 192.3.0.3. Cord trimmers are not allowed. Replace damaged plants per Item 192.0.9 ☑ Maintain grasses and weeds at 24" maximum height. Eradicate all vines regardless of height. Eradicate invasive shrubs and trees as directed. Method must be either a spot-treatment chemical application such as a wick applicator or manual hand pulling of weeds and vines. Spray applicators are not allowed. Hand-pull previously treated dead plants over 24" tall.		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
193.3.A.5. **MOWING, TRIMMING, AND EDGING** (From back of curb, retaining wall, barrier, and riprap to bed preparation areas, otherwise 6' width around outside edge of bed preparation areas, around and between planting bed preparation areas, including areas around any structures within the outer limits adjacent to the roadway) DO NOT MOW, TRIM, OR EDGE WITHIN 3' of ANY TREE	MOW EIGHT TIMES PER 365 DAY PERIOD, ONCE PER MONTH, DURING THE LAST WEEK OF: APRIL, MAY, JUNE, JULY, AUGUST, SEPTEMBER, OCTOBER, NOVEMBER																																															
193.3.A.6. **STAKING, GUYING, AND BRACING OF PLANTS** (Remove plant stakes and all appurtenances within last 30 days of this schedule, unless otherwise directed by engineer)		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
193.3.B. **PLANT REPLACEMENT***				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓				✓
193.3.C. **VEGETATIVE WATERING** (See PLANTING AND ESTABLISHMENT SHEET 1 of 8, VEGETATIVE WATERING SCHEDULE FOR TREES, SHRUBS, VINES) and/or (See PLANTING AND ESTABLISHMENT SHEET 2 of 8 VEGETATIVE WATERING SCHEDULE FOR PALMS ONLY)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
193.3.D. **IRRIGATION SYSTEM OPERATION AND MAINTENANCE**		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
1009-2005 **SOIL AMENDMENT (TYPE IV)** (PLANTING AND ESTABLISHMENT SHEETS 5 AND 6 of 8, each application will be paid for separately)	✓																																												✓			
1009-2006 **SOIL AMENDMENT (TYPE V)** (PLANTING AND ESTABLISHMENT SHEETS 5 AND 6 of 8, each application will be paid for separately)																																									✓							
LITTER AND DEBRIS COLLECTION AND DISPOSAL (Includes planting bed preparation areas and designated mowing limits. In addition, keep all inlets within or near planting bed preparation areas free of debris and litter)		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓

* Remove any materials damaged by actions described in Item 7.14.A. Removal and disposal of damaged materials is incidental to Item 193.

✓ = Work required during defined period of timeline. All work must be completed for entire project.

Texas Department of Transportation
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HOUSTON DISTRICT

PLANTING AND ESTABLISHMENT

SHEET 8 of 8

ESTABLISHMENT

FILE:	FED DIV	STATE	PROJECT NUMBER			SHEET
	6	TEXAS				
ORIGINAL:	DIST	COUNTY	CONTROL	SECT	JOB	HIGHWAY
	12	HARRIS	3256	02	078, ETC	BW 8

STD K-4