# The Effects of Using Compost as a Preventive Measure to Mitigate Shoulder Cracking: Laboratory and Field Studies

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**16. Abstract**

Compost materials, given their moisture affinity, fibrous and low permeability characteristics, could provide stabilization of natural expansive subgrades by mitigating shrinkage cracking. In order to understand possible mechanisms of this stabilization, a research study was conducted in both laboratory and field phases to evaluate the effectiveness of compost material treatments to soils. This research report summarizes both phases' results, which include laboratory and field studies to evaluate Dairy Manure Compost (DMC) and Biosolids Compost (BSC) manufactured topsoils (CMT) to lessen shoulder subgrade cracking. During the field phase, data was collected from embedded moisture and temperature sensors, digital image surface cracking studies, visual observations of paved shoulder cracking, runoff quality, and surficial erosion surveys of all sixteen CMT test plots and one control test plot. Both composts were mixed with the subsoils at different proportions and dimensions in these plots. The field data was collected for eighteen months and then analyzed with statistical comparison tests, which indicated that the BSC amendments provided the best subsoil enhancements by controlling moisture and temperature fluctuations from surrounding environments and thereby reducing shrinkage cracking in subsoils and in adjacent paved shoulders. The DMCs were less effective in mitigating shrinkage cracking, due to low amounts of organic contents, also resulting in erosion problems. The final outcome of this research is the recommendation of BSC material to treat 4 in. of top subgrade shoulders for a width of 10 ft in order to control or mitigate soil shrinkage cracking.

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# DISCLAIMER

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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Desiccation cracks in expansive cohesive soils are generally formed during the drying process of fine grained cohesive soils. These cracks allow surface runoff water infiltration into subsoil layers and eventually weaken both the base and subgrade of pavements. These cracks often appear on unpaved shoulder subgrades where they are vulnerable to further drying due to direct exposure to high temperature and wind conditions. These cracks, if not controlled, will eventually propagate under and upward through the paved shoulder and travel lanes as seen in Figure 1.1.

As a result, runoff water will infiltrate into the soil layers underneath the cracked paved shoulders and pavements. Both softening and volume changes of the underlying soils here could result in severe distress to pavements which will deteriorate the structural performance of pavements. Surficial cracks in both the longitudinal and transverse directions can be seen in Figure 1.2. Hence, protection and maintenance of unpaved shoulder subsoils are key elements to the protection of the integrity of the roadways and related paved structures (Booze-Daniels et al. 2000).

Effective remediation methods must be immediately applied to prevent desiccation cracking of subsoils. Several chemical and mechanical treatment methods have been used to stabilize expansive shoulder subgrades. However, these methods have their own limitations and restrictions. Some are expensive, some less effective and some are not suitable in sulfate rich soils. Compost materials, given their moisture affinity (hydrophilic), low permeability and fibrous characteristics, are expected to reduce swell and more importantly shrinkage behaviors of underlying natural subsoils by encapsulating and reinforcing them. As a result, pavement shoulder cracking could be mitigated.

Figure 1.1: Shoulder cracking of SH 108 (Transverse Cracks)

Figure 1.2: Longitudinal and transverse cracks

Compost is a disinfected and a stable decomposed organic material obtained from the composting process of different types of wastes. Composting is recognized as one of the innovative ways of recycling waste materials, by converting materials rich with pathogens to materials that could be effectively used in various day to day applications such as landscaping and erosion control. Composting has the ability to improve the chemical, physical and biological characteristics of soils as shown in Table 1.1.

Table 1.1: Benefits of compost addition identified by various investigators

| | **USCC** | **US EPA** | **Mitchell, D.** | **Univ. of Georgia** | **Univ. of Florida** |
|---|---|---|---|---|---|
| Improves soil structure, porosity, bulk density | ✓ | | ✓ | | |
| Increases water holding capacity of soil | ✓ | ✓ | | ✓ | ✓ |
| Increases infiltration and permeability of soils | ✓ | | ✓ | ✓ | |
| Erosion control | ✓ | | ✓ | ✓ | |
| Helps moderate soil temperatures | | | | | ✓ |
| Adds organic bulk and humus to regenerate poor soils | | ✓ | ✓ | ✓ | ✓ |
| Helps suppress plant diseases and pests | | ✓ | | | |

(Modified from Jennings et al., 2003)

Currently, many state Department of Transportation agencies (DOTs) have utilized compost in highway construction for different applications. Table 1.2 presents a summary of these projects, compost types and application areas used by the selected state DOT. The Table provides projects that illustrate a variety of potential applications for compost, as well as projects from a variety of geographical regions, representing different climatic conditions and soil types (CCREF/USCC, 2001).

Table 1.2: Literature review on recent compost applications in highways

| **Reference** | **Compost materials** | **Application areas** |
|---|---|---|
| Connecticut DOT | Compost consisting of mushroom substrate | Landscape Plantings |
| Connecticut DOT | Compost consisting of yard trimmings | Wetlands Creation |
| Florida DOT | Biosolids and yard trimmings, biosolids and Municipal Solid Waste (MSW)<br>Yard trimmings only | Turf Establishment |
| Idaho DOT | Dairy Manure Compost | Vegetation Establishment |
| New Hampshire DOT | Compost consisting of Municipal Solid Waste (MSW)<br>and commercially produced compost | Wildflower & Roadside Plantings |
| Oregon DOT | Yard trimmings compost | Erosion Control |
| Texas DOT | Dairy Manure Compost | Revegetation Difficult Slopes |
| Virginia DOT | Yard trimmings compost | Wildflower Plantings |
| Washington State DOT | Biosolids Compost | Soil Bioengineering |

From the literature review listed in Table 1.2, compost has been used in various applications including erosion control, revegetation, biofiltration, bioremediation and landscaping. Since compost is rich in nutrients and fibrous materials and exhibits moisture affinity characteristics, it is theorized that compost can be used to stabilize expansive soils in order to control desiccation cracks on the adjoining soil surfaces under the pavements. However, no studies were either available or conducted to address this application of compost to reduce subsoil cracking. In this research, an attempt was made for the first time to study the potential benefits of compost amendments to mitigate cracking in shoulder subgrades which are expansive in nature.

## 1.2 Objective and Scope of the Research

The main objective of the research was to use composts to treat expansive subsoils in order to mitigate the shrinkage cracking in them. The increasing use of recycled materials and byproducts in highway construction and maintenance projects has resulted in better performance of highways and enhanced recycling applications of recycled materials. State highway agencies have been evaluating and studying suitable recycled materials and by-products in highway construction and maintenance operations for many years. One of the recycled materials that can provide similar benefits is compost material.

Several research groups in the United States as well as in other parts of the world have effectively demonstrated the use of compost for various landscape and erosion control applications in highway constructions. It can also be discerned from the review of literature that the use of compost is recommended in order to reduce the landfilling of these source materials. This will save cost and space. One of the methods of using recycled solid wastes in an environment friendly way is to use them in appropriate highway maintenance projects in order to reduce the cost of highway construction and maintenance (Shelburne et al., 1998).

Considering all the above, this research study was developed to address the use of these compost materials for better encapsulation of adjoining shoulder soils in order to mitigate both shoulder subsoil and pavement cracking, in dry to semi-dry environments. This study has focused on two types of inexpensive recycled composts; Biosolids Compost (BSC) and Dairy Manure Compost (DMC), both in pure and blended forms, to be used to amend adjoining shoulder cover soils to mitigate shoulder cracking.

Several parameters were monitored as a part of an experimental design that explored the swell, shrinkage and strength parameters of the amended soils in the laboratory environment. Performance parameters such as shrinkage and swelling of shoulder subgrades, moisture and temperature fluctuations as well as erosion and runoff qualities were monitored in field conditions. Parameters such as moisture and temperature readings were used to verify the encapsulation effects of composts to the underlying soil layers. Shrinkage, elevation surveys and erosion analyses were used to address the survivability of the cover materials to elements, swell and shrinkage movements. Water runoff analysis was conducted to monitor environmental impacts of using these materials in the field. Results on these investigations are covered in this report.

## 1.3 Tasks Followed

To accomplish this research, the following tasks were planned and performed:

1. Perform a literature review on various composts and their applications in highway construction and maintenance.
2. Conduct comprehensive laboratory investigations to address geotechnical characteristics including swell, shrinkage, and strength properties of composts and compost amended soils at two different proportions.
3. Analyze and rank the composts based on their enhancements from laboratory test results.
4. Construct seventeen test plots with various compost amendments at different widths and thicknesses and then instrument the sites to evaluate temperature and moisture patterns in the soils.
5. Perform elevation surveys and digital image studies periodically to assess the erosion potential and desiccation cracking at the surfaces.
6. Monitor paved shoulder cracking patterns to evaluate the effectiveness of the cover materials.
7. Observe vegetation growth to address the enhancing effects of compost amendments to the soils.
8. Conduct surface water runoff analysis periodically to compare water quality from compost treated and the Control Plots.
9. Perform statistical ANOVA and ranking analyses on collected test data to evaluate each compost material in providing effective treatments of the expansive soil.
10. Prepare a final comprehensive research report summarizing the present research findings.

### 1.4 Organization of the report

This report is the second and final comprehensive Research Report (RR-2) for the research project and consists of six chapters.

Chapter 1 provides an introduction, background history explaining the significance of the project, research objectives, and report organization to provide a frame work of the completed research.

Chapter 2 covers a brief overview of the laboratory studies conducted on both Compost Manufactured Topsoils (CMTs) utilizing Dairy Manure Compost and Biosolids Compost. This chapter discusses the selection of the compost materials, laboratory studies and ranking analysis for the CMTs.

Chapter 3 presents information pertaining to the field studies. Such information includes temperature and moisture fluctuations, erosion, shrinkage analysis, paved shoulder cracking, vegetation and water runoff quality. Test methods, procedures and instrumentation are also discussed in this chapter.

Chapter 4 presents the results of the physical and chemical analyses from runoff samples collected from the Control Plot, one Biosolids Compost plot and one Dairy Manure Compost plot. These results are compared with other highway runoff quality studies conducted in Texas and benchmark values established by the USEPA. Potential causes of high concentrations in these measurements are also explained.

Chapter 5 presents a comprehensive analysis of the findings from the field studies. This chapter also discusses the methods of analysis. A ranking analysis was performed to evaluate the overall performance of each plot.

Chapter 6 presents the summary of findings and recommendations of the experimental research studies and the status of ongoing implementation studies.

# CHAPTER 2
# AN OVERVIEW OF LABORATORY STUDIES

## 2.1 Introduction

An overview on laboratory studies presented in this chapter is summarized from the first research report, TxDOT-4573-RR1. Since the intent of this report is to investigate the overall performance of compost material covers as a preventive measure of shoulder cracking, the first part of the project, laboratory studies was devoted to the selection of compost materials. A summary of the laboratory results and ranking analysis is presented in this chapter.

## 2.2 Selection of composts

There were several types of compost initially considered in this study. However, not all composts can be used for a specific purpose or with a particular soil type. Some work best when it is tailor-made or specially designed to fit the user's needs (USEPA,1997). Compost can be produced from many feedstocks and they are typically rich in organic matter. Factors which affect the selection and use of composted material include feedstock properties, regulations, product uniformity, contaminant levels and economic considerations relating to distribution and utilization benefits (Shiralipour et.al., 1992). The user must also consider specifications agencies use in the specific area. The specifications for compost should apply to a range of characterictics and require manufacturer testing for stability, maturity, organic and nutrient content, pH, salts, density, infiltration and particle size (Black et al., 1999).

A study conducted by the University of Texas at Austin was used as the basis for the compost material selection in this research. The study conducted by UT Austin indicates that only two composts, Dairy Manure Compost and Biosolids Compost, met or came close to the specifications of TxDOT and the United States Environmental Protection Agency (USEPA) for using them as potential soil amendments (Kirchhoff, 2002). The following section provides brief descriptions of both composts.

### 2.2.1 Biosolids Compost (BSC)

Biosolids are nutrient-rich organic materials resulting from the treatment of effluent and sludge from the wastewater treatment process. Sewage sludge is a putrefactive, concentrated, aqueous suspension of biodegradable, partially biodegradable and essentially non-biodegradable solids with associated absorbed and dissolved matter, exhibiting similar ranges of degradability characteristics (Bruce et al., 1989).

This material meets both TxDOT compost requirements and EPA Part 503 environmental characteristics requirements for potential use to mix with soils. Hence, this material was selected as one of the two composts studied in this research. The trade name of this material is “Dillo Dirt”.

### 2.2.2 Dairy Manure Compost (DMC)

Dairy Manure Compost is produced through the activity of aerobic microorganisms. The microorganisms generate heat, water and carbon dioxide as they transform the raw materials into stable materials (USCC, 2001). These microorganisms require water, oxygen and food at optimum levels in order to accelerate the process of aerobic digestion of dairy manure. The end-product is stable, reduced in quantity and free from offensive odors. When used appropriately, Dairy Manure Compost can improve biological and chemical properties (Schmitt et al., 1998). Bacteria and humus present in dairy manure have the ability to increase the microbial activity in the soil. This helps to improve soil physical properties (Diaz et al., 1993). Dairy Manure Compost for this project was provided by Producers Compost in Erath County, Texas.

## 2.3 Summary of laboratory test results

This section summarizes a comprehensive analysis of both basic and engineering laboratory test results conducted on both compost and amended soils. This analysis evaluated the potential of each compost material to provide enhancements to the soil properties. The effectiveness of each compost material and their influence on PI, strength, permeability, swell and shrinkage strain properties on the Control Soil (CS) are also explained. Ranking analysis based on targeted soil properties was performed to determine compaction moisture contents for field test plots. More details on these test results can be found in Research Report 1 (TxDOT-4573-RR1). Table 2.1 defines various notations used to identify the compost amended soils and the Control Soil in this research report.

Table 2.1: Definitions

| Designation | Percents of Constituents |
|---|---|
| CS | Pure Control Soil |
| CMT 1 | 75 % Dairy Manure Compost and 25% Control Soil |
| CMT 2 | 100 % Dairy Manure Compost |
| CMT 3 | 20 % Biosolids Compost and 80% Control Soil |
| CMT 4 | 30 % Biosolids Compost and 70% Control Soil |

### 2.3.1 Atterberg Limits

Atterberg Limits of the field soil were determined by performing TxDOT Test Method Tex-104-E to determine the Liquid Limit and Tex-105-E to determine the Plastic Limit. The difference between these limits is termed as the Plasticity Index (PI) per Tex-106-E. The Plasticity Index is generally used to classify the plastic nature and expansive potential of soils. Table 2.2 presents the Atterberg Limits of the control and amended soils.

Table 2.2: Atterberg Limits of the control and compost amended soils

| Soil Description | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index |
|---|---|---|---|
| CS | 44 | 16 | 28 |
| CMT 1 | 38 | 20 | 18 |
| CMT 2 | 36 | 24 | 12 |
| CMT 3 | 60 | 25 | 35 |
| CMT 4 | 72 | 35 | 37 |

Table 2.2 shows that the Plasticity Index values of the Dairy Manure Compost amended soils decreased and Plasticity Index values of the Biosolids Compost amended soils increased when compared to the Control Soil. The decrease in the Plasticity Index values of the Dairy Manure Compost are attributed to the presence of coarse sized particles. The increase in the Plasticity Indices is attributed to the presence of hydrophilic natured particles in the Biosolids Compost.

### 2.3.2 Direct Shear Test

The shear strength parameters of a soil can be determined in the laboratory by conducting a Direct Shear Test as per ASTM D3080 on compacted soil specimens at three different confining pressure conditions of 14, 28, and 42 psi, respectively. Table 2.3 summarizes these direct shear test results of control and amended soils in the form of cohesion intercept and friction angle. These results are reported for both compaction moisture conditions close to optimum and wet of optimum levels.

Table 2.3: Shear strength parameters of the control and compost amended soils

| Soil Type | @ Optimum | | @ Wet of Optimum | | Shear Strength ($\tau$) ** | |
|---|---|---|---|---|---|---|
| | Cohesion (c) (psi) | Friction Angle, $\phi$ in degrees | Cohesion (c) (psi) | Friction Angle, $\phi$ in degrees | Optimum (psi) | Wet of Opt. (psi) |
| CS | 17.1 | 3.0 | 12.2 | 2.5 | 17.8 | 12.9 |
| CMT 1 | 15.5 | 21.0 | 12.4 | 13.0 | 21.1 | 15.7 |
| CMT 2 | 8.5 | 26.0 | 6.0 | 23.0 | 15.6 | 12.2 |
| CMT 3 | 20.8 | 22.5 | 17.4 | 19.0 | 26.9 | 22.4 |
| CMT 4 | 16.8 | 23.5 | 16.1 | 19.5 | 23.2 | 21.2 |

**$\tau = c + \sigma \tan \phi$, where $\sigma$= 14 psi

The Control Soil was observed to have very low friction angles at optimum and wet of optimum moisture contents. These results are consistent with those expected for a medium clay. The Dairy Manure Compost exhibited lower cohesion and higher friction angles due to the coarser compost particles. The Biosolids Compost amended soils showed higher cohesion values and higher friction angles also due to the coarser compost particles. This can be attributed to the presence of yard trimming and coarse sized particles in the BSC material. Based on the shear strength property at 14 psi confinements, both CMT 3 and CMT 4 (BSC materials) are slightly higher than CMT 1 and CMT 2 (DMC materials). Overall, moderate strength enhancements were recorded when the Control Soil was stabilized with composts.

### 2.3.3 One-Dimensional Free Swell Test

The One-Dimensional Free Swell Test (ASTM D4546) measures the amount of heave in the vertical direction of a laterally confined specimen in a rigid chamber. The test results are presented in Table 2.4.

Table 2.4: Free vertical swell strains of the control and compost amended soils

| Soil Description | @ Optimum Moisture Content (%) | @ Wet of Optimum Moisture Content (%) |
|---|---|---|
| CS | 11.4 | 5.6 |
| CMT 1 | 24.6 | 22.8 |
| CMT 2 | 23.8 | 22.5 |
| CMT 3 | 27.9 | 23.2 |
| CMT 4 | 31.2 | 28.4 |

The compost materials have more water holding capacity than the Control Soil. Because of this, when the soil sample was saturated, the compost amended soils exhibited more swelling. These numbers demonstrate that the Biosolids Compost has more water holding capacity than the Dairy Manure Compost and the swell percentage increased with the percentage increase of compost. High swell numbers in the Biosolids Compost amended soils are attributed to the presence of higher amounts of organic matter present.

### 2.3.4 Linear Shrinkage Bar Test

The Linear Shrinkage Bar Test as per TxDOT Test Method Tex-107-E was conducted to measure the linear shrinkage strains of the soils. This test provides a measure of linear shrinkage of a bar of soil paste in the bar type mold. The results are summarzed in Table 2.5.

Table 2.5: Linear shrinkage strain values for the control and compost amended soils

| Soil Description | @ Optimum | @ Wet of Optimum | @ Liquid Limit |
|---|---|---|---|
| CS | 14.0 | 17.0 | 23.4 |
| CMT 1 | 6.0 | 8.0 | 10.0 |
| CMT 2 | 4.2 | 4.8 | 5.7 |
| CMT 3 | 5.8 | 6.5 | 14.3 |
| CMT 4 | 10.7 | 12.2 | 18.1 |

The shrinkage strain values in the DMC amended soils decreased with an increase in dairy manure content at all three moisture content values as shown in Table 2.5. This decrease is due to the reductions in plasticity characteristics.

The BSC amended soils exhibited higher shrinkage strain values than the DMC amended soils. This increase is due to the presence of higher natural moisture content in these soils as shown in Table 2.4. Higher moisture presence is attributed to organic matter present in these soils, which are known to attract and contain moisture. Though the BSC amended soils had higher initial natural moisture contents, the shrinkage strain values were still low because of the presence of wood chips and yard trimmings. These natural fibers provide shrinkage resistance to natural soils. Overall, compost amendments resulted in the decrease of linear shrinkage strain potentials of the Control

Soil. This indicates that the compost amendment has the potential to reduce desiccation or shrinkage cracking in soils.

### 2.3.5 Permeability Test

Permeability refers to the movement of water within the soil and this test was conducted as per ASTM D2434. The water movement will have profound effects on the soil properties, drainage conditions and moisture holding capacities. In predicting the flow of water in soils, it is imperative to evaluate the coefficient of permeability for a given soil sample. Table 2.6 presents the test results.

Table 2.6: Coefficient of permeability of the control and compost amended soils

| Soil Description | @ Optimum (cm/sec) | @ Wet of Optimum (cm/sec) |
|---|---|---|
| CS | $1.2\times10^{-8}$ | $3.0\times10^{-9}$ |
| CMT 1 | $4.2\times10^{-8}$ | $4.3\times10^{-9}$ |
| CMT 2 | $8.9\times10^{-8}$ | $8.7\times10^{-9}$ |
| CMT 3 | $7.8\times10^{-8}$ | $9.7\times10^{-9}$ |
| CMT 4 | $1.2\times10^{-7}$ | $7.8\times10^{-8}$ |

All the soils were observed to have higher permeability values at optimum moisture content than at wet of optimum moisture content. An increase in the compaction moisture content results in a decrease in the soil permeability. This decrease is attributed to the soil structure, which becomes dispersed or parallel oriented soil structure at high moisture contents. Such parallel oriented soil structures impede the hydraulic flow through them.

Soils mixed with the Biosolids Compost exhibited low permeability values. This is because soils with high plasticity properties have a thicker double layer, possess greater dispersive structure, and hence exhibit lower permeability. The reduced water absorption capacity indicates a decrease in the double layer thickness and therefore an increase in soil permeability (Mitchell, 1993).

The Dairy Manure Compost amended soils exhibited slightly higher permeability values than the Control Soil. This is because the mean diameter ($D_{50}$) of Dairy Manure Compost is more than $D_{50}$ of the Control Soil. Permeability property depends on soil size and hence high permeability properties were obtained for Dairy Manure Composts.

## 2.4 Ranking Analysis

The following scale system was used in which the transformation of each soil property from problematic levels to non-problematic levels is assigned a numeric ranking. Non-problematic soil property levels here are those that correspond to lower shrinkage cracking conditions. The magnitude of ranking is based on the severity of the soil problem. The worst soil condition is given a rank of 1 and the best soil condition is given a rank of 5. In between conditions, ranks of 2 to 4, are assigned for different ranges of soil properties. Table 2.7 summarizes the soil characterization based in different soil properties.

Table 2.7: Soil characterization based in different properties of the soils

| PI** | Vertical Swelling Strain (%) * | Linear Shrinkage Strain (%) * | Shear Strength, psi (kPa) ** | Coefficient of Permeability (cm/sec) | Rank | Soil Condition |
|---|---|---|---|---|---|---|
| $0 \le PI \le 5$ | 0 - 0.5 | < 5.0 | > 28 (200) | $<10^{-8}$ | 5 | Best |
| $5 < PI \le 15$ | 0.51 - 1.5 | 5.0 – 8.0 | 21–28 (150–200) | $10^{-7}$ - $10^{-8}$ | 4 | Better |
| $15 < PI \le 25$ | 1.51 – 4.0 | 8.1 – 12.0 | 14–21 (100–150) | $10^{-6}$ - $10^{-7}$ | 3 | Good |
| PI > 25 | > 4.0 | 12.1 – 15.0 | 7–14 (50–100) | $10^{-5}$ - $10^{-6}$ | 2 | Poor |
| PI > 50 | > 8.0 | >15.0 | 0–7 (0–50) | $10^{-4}$ - $10^{-5}$ | 1 | Worst |

* Nelson and Miller, 1992; **Wattanasanticharoen, 2000

Table 2.8 presents the ranking of the Control Soil and CMTs based on both physical and engineering test results. From the Table, it can be observed that all the soils have an equal or better ranking at the optimum moisture content level than at the wet of optimum moisture content level. All CMTs have equal or higher impact values than the Control Soil. CMT 2 has the best ranking (3.3) when compared to the other amended soils. DMC has enhanced the Control Soil ranking from a poor (2.6) to a good (3.6) ranking. Likewise, BSC (at 20% dosage level) has enhanced the Control Soil ranking from 2.6 to 3.2.

Table 2.8: Ranking of the control and compost amended soils based on test results

| Soil Type | w% | PI | FS | LS | τ | k | IV[1] | IV[2] | IV[3] |
|---|---|---|---|---|---|---|---|---|---|
| CS | O | 2 | 1 | 2 | 3 | 5 | 2.6 | 2.1 | 2.3 |
| | W | 2 | 2 | 1 | 2 | 5 | 2.4 | 2 | 2 |
| CMT 1 | O | 3 | 1 | 4 | 3 | 5 | 3.2 | 2.9 | 2.9 |
| | W | 3 | 1 | 4 | 3 | 5 | 3.2 | 2.9 | 2.9 |
| CMT 2 | O | 4 | 1 | 5 | 3 | 5 | 3.6 | 3.3 | 3.3 |
| | W | 4 | 1 | 5 | 2 | 5 | 3.4 | 3.2 | 3.1 |
| CMT 3 | O | 2 | 1 | 4 | 4 | 5 | 3.2 | 2.9 | 3 |
| | W | 2 | 1 | 4 | 4 | 5 | 3.2 | 2.9 | 3 |
| CMT 4 | O | 2 | 1 | 3 | 4 | 4 | 2.8 | 2.5 | 2.7 |
| | W | 2 | 1 | 2 | 3 | 5 | 2.6 | 2.1 | 2.3 |

Where, k - Coefficient of permeability (cm/sec); τ - Shear Strength (kPa);

- $I.V^1 = 0.2\,(PI) + 0.2\,(FS) + 0.2\,(LS) + 0.2\,(\tau) + 0.2\,(k)$
- $I.V^2 = 0.15\,(PI) + 0.3\,(FS) + 0.3\,(LS) + 0.15\,(\tau) + 0.1\,(k)$
- $I.V^3 = 0.15\,(PI) + 0.25\,(FS) + 0.25\,(LS) + 0.25\,(\tau) + 0.1\,(k)$

The laboratory test results yielded the following four important conclusions:

1. Compost amendments produced a reduction in the linear shrinkage strains of the Control Soil.
2. Compost amendments produced moderate increases in the shear strength of the soil.
3. Compost amendments produced a considerable increase in swell strain potentials of the Control Soil.
4. Compost amendments produced a slight decrease of permeability properties in soils.

Considering the decrease in shrinkage strain potentials and strength enhancements, it is expected that these amendments in field conditions would lead to less desiccation cracks in adjoining shoulder soils, which are the primary causes of paved shoulder and travel lane subgrade soil cracking. Hence, field test plots were recommended to test the same four materials at different depths and widths. Details of these studies are explained in the next few chapters.

## 2.5 Summary

A summary of laboratory test methods and results of both the Control Soil and CMTs were presented and analyzed in this chapter. All CMTs showed significant improvement in the soil properties with Dairy Manure Compost amendments yielding slightly better improvements than Biosolids Compost amended soils in the laboratory environment. These materials were considered for further use in field applications which are described in the next chapter.

# CHAPTER 3
# CONSTRUCTION OF FIELD PLOTS AND MONITORING

## 3.1 Introduction

Due to the improvement to the Control Soil based on the laboratory results, the second phase of the research investigation was designed and implemented to evaluate the performance of the CMTs in field conditions. The Control Soil and CMTs were mixed at the same proportions that were used in the laboratory investigations. These were mixed into and compacted over local soils to serve as a cover material for the existing soils. This chapter describes the site construction, instrumentation and site evaluation procedures followed in the research.

## 3.2 Site construction

To accomplish this research, a field test site was selected on State Highway 108 near Stephenville, TX (Figure 3.1). Personnel from TxDOT and the University of Texas at Arlington participated in the selection of the test plots.

Prior to construction, soil from the test plots and both composts were collected and evaluated in the laboratory. Both physical and engineering properties of the CMTs and the Control Soil were first determined in the laboratory. These properties were then analyzed by the ranking scale system, which were presented in Chapter 2. Based on the test results, two composts, Dairy Manure Compost and Biosolids Compost, were recommended for the field studies. These composts were mixed with the Control Soil following the recommended proportions to form four types of CMTs as covers for different test plots. These CMTs were used as shoulder cover materials by studying their erodability and shrinkability characteristics and evaluating their performance in field conditions.

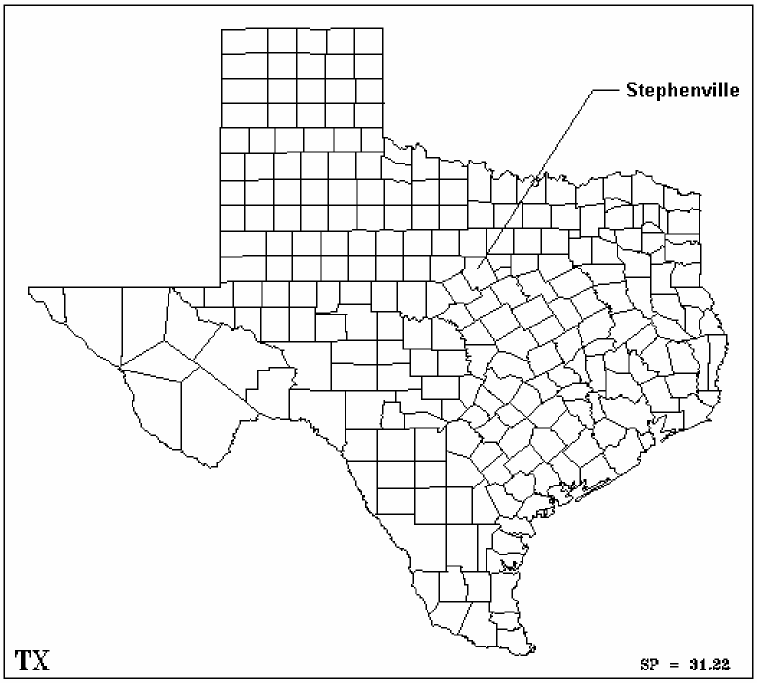



Figure 3.1: Location of SH 108 near Stephenville in Erath County, Texas
(Source: Indiana State University)

In the field, sixteen test plots with CMTs of different widths and thicknesses were constructed and studied. Two widths (5 ft and 10 ft) and two thicknesses (2 in. and 4 in.) were studied. One Control Plot (CP) with no CMT was included for comparison studies and this plot was established as the untreated or Control Plot. To simplify the names of all variables, the following notation is used throughout the report to identify various CMTs with different widths and thicknesses. Every sample was assigned a notation set in the form of CMT4-10-4 where the first notation set, CMT4, indicates the type of CMT used as the top soil cover. The second part of the notation describes the treatment width (for example, 10 indicates 10 foot wide) and the third number shows the treatment thickness in terms of in. (for example, 4 indicates 4 inch thickness). Table 3.1 presents details of these test plots.

Table 3.1: Details of test plots

| **Plot** | **Plot Name** | **Material** | **Shoulder width (ft)** | **Thickness (in)** |
|---|---|---|---|---|
| 1 | CMT4-10-4 | BSC | 10 | 4 |
| 2 | CMT3-10-4 | BSC | 10 | 4 |
| 3 | CMT2-10-4 | DMC | 10 | 4 |
| 4 | CMT1-10-4 | DMC | 10 | 4 |
| 5 | CMT4-10-2 | BSC | 10 | 2 |
| 6 | CMT3-10-2 | BSC | 10 | 2 |
| 7 | CMT2-10-2 | DMC | 10 | 2 |
| 8 | CMT1-10-2 | DMC | 10 | 2 |
| 9 | CMT4-5-2 | BSC | 5 | 2 |
| 10 | CMT3-5-2 | BSC | 5 | 2 |
| 11 | CMT2-5-2 | DMC | 5 | 2 |
| 12 | CMT1-5-2 | DMC | 5 | 2 |
| 13 | CMT4-5-4 | BSC | 5 | 4 |
| 14 | CMT3-5-4 | BSC | 5 | 4 |
| 15 | CMT2-5-4 | DMC | 5 | 4 |
| 16 | CMT1-5-4 | DMC | 5 | 4 |
| 17 | CP-10-4 | CS | 10 | 4 |

The field test plot construction began on March 27, 2003 and was completed on March 28, 2003. The test site is approximately 1275 feet in length and is located between the ROW boundary fence and paved shoulder edge on the west side of the highway. One CP and 16 CMT test plots built with the four different CMTs as shoulder covers were constructed at the test site. Each plot was 50 ft long with a transition zone of 25 ft to separate each plot in order to ensure that the adjacent compost materials would not affect the field results on any other test plot (Figure 3.2).

In each plot, compost was mixed with the natural top soil at targeted proportions and then compacted into CMT plots of different dimensions with a smooth roller. Each test plot was instrumented with three moisture probes and one temperature probe to monitor fluctuations in the subsoils. In addition, erosion, shoulder cracking and leachate analysis were also periodically investigated. These are described later in this chapter.

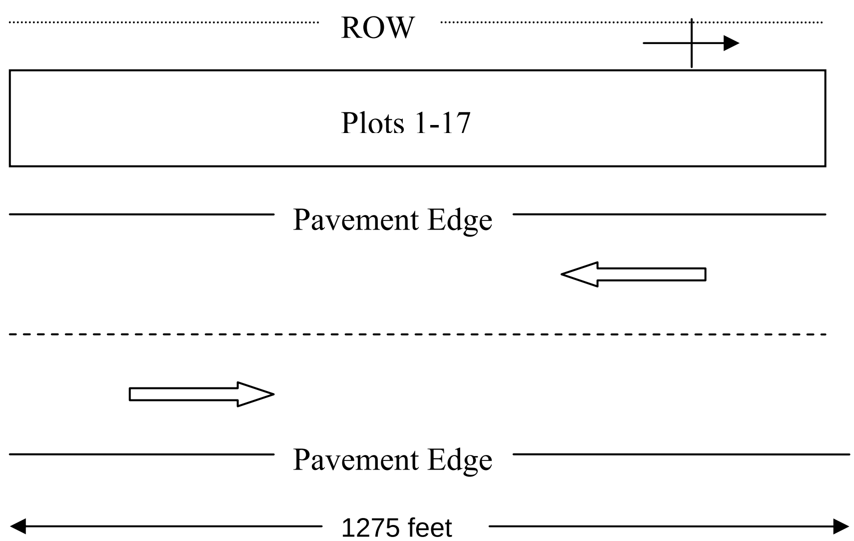



Figure 3.2: Illustration of field site

### 3.3 Field tests on the test plots

Since the main objective of this research was to design various CMT test plots of different sizes and then monitor the performance of these plots, an attempt was made to collect extensive data from all of the test plots. The data collected in the field covers: (1) shrinkage analysis (2) moisture and temperature fluctuations (3) surface erosion (4) vegetation growth (5) paved shoulder crack propagation and (6) environmental assessments. The data collected was statistically analyzed to evaluate the effectiveness of the selected compost materials, widths, and thicknesses as cover materials. The following sections describe detailed evaluation procedures used throughout this research.

### 3.3.1 Temperature and moisture data

Instrumentation of the test plots played an important role in understanding the effectiveness of compost materials for providing moisture and temperature encapsulation of the natural subgrade. Encapsulation means that the compaction moisture content of subgrade soils does not vary significantly when compared with the moisture variations of a Control Plot due to seasonal changes. To investigate the encapsulation mechanisms, moisture and temperature probes were installed immediately after construction of the test plots (Figure 3.3).

The moisture sensor used here works on the principle of Time Domain Transmissometry (TDT) technology and provides volumetric moisture contents. It measures the one-way propagation time. The pulse reading is observed at the other end of the transmission line from the transmitter of the sensor. The propagation time of an electromagnetic wave along a given length of transmission line is proportional to the square root of the permittivity of the medium the transmission line is immersed in. For the medium of soil/water/air, in this project the permittivity of the water dominates the mixture of permittivity and the measurement can then be used to determine the volumetric water content of the soil mixture. Volumetric moisture contents are related to gravimetric moisture contents by the density of the soil medium. The relationship is shown in the following equation.

$$\theta_G = \theta_V * \frac{\rho_W}{\rho_S}$$

Where $\theta_G$ = Gravimetric soil moisture content;

$\theta_V$ = Volumetric soil moisture content;

$\rho_w$ = Density of water and

$\rho_s$ = Bulk density of soil.

Sensors were placed after the construction of the test plots rather than during construction due to the sensitivity of the equipment against the weight of the construction equipment. Three moisture sensors were placed in each test plot at three different depth intervals, 6 in. (Gropoint 2), 12 in. (Gropoint 1), and 18 in. (Gropoint 3), and one temperature sensor was placed close to the ground surface at the 6 in. depth. The sensors placement is shown in Figure 3.4. Sensors were carefully placed such that there were no air gaps between the sensor and the surrounding soil. In other words, the sensor rods are placed inside the soil mass. The excavated soil was then placed back in the hole and compacted in short lifts (4 in.). Extreme care was taken to ensure the compaction was similar to the adjoining subsoils.

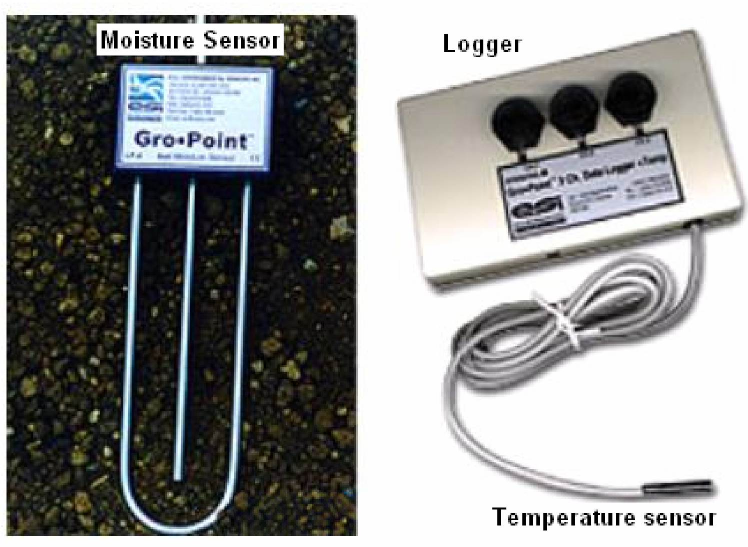



Figure 3.3: Temperature and moisture probes and a logger

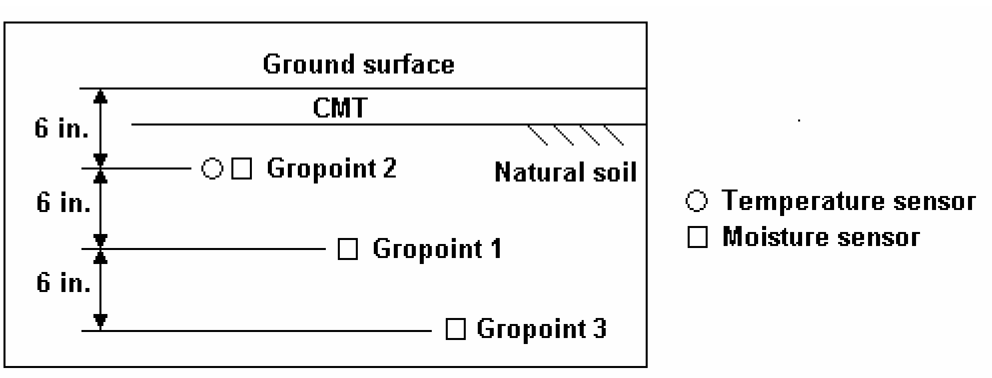



Figure 3.4: Placement of sensors

Both moisture and temperature probes provide real time volumetric moisture content and temperature data. The data was stored in a data logger stationed at each test plot and the data was downloaded to a computer during site visits. A typical example of the moisture and temperature data from a sensor collected till August 2004 is presented in Figure 3.5.

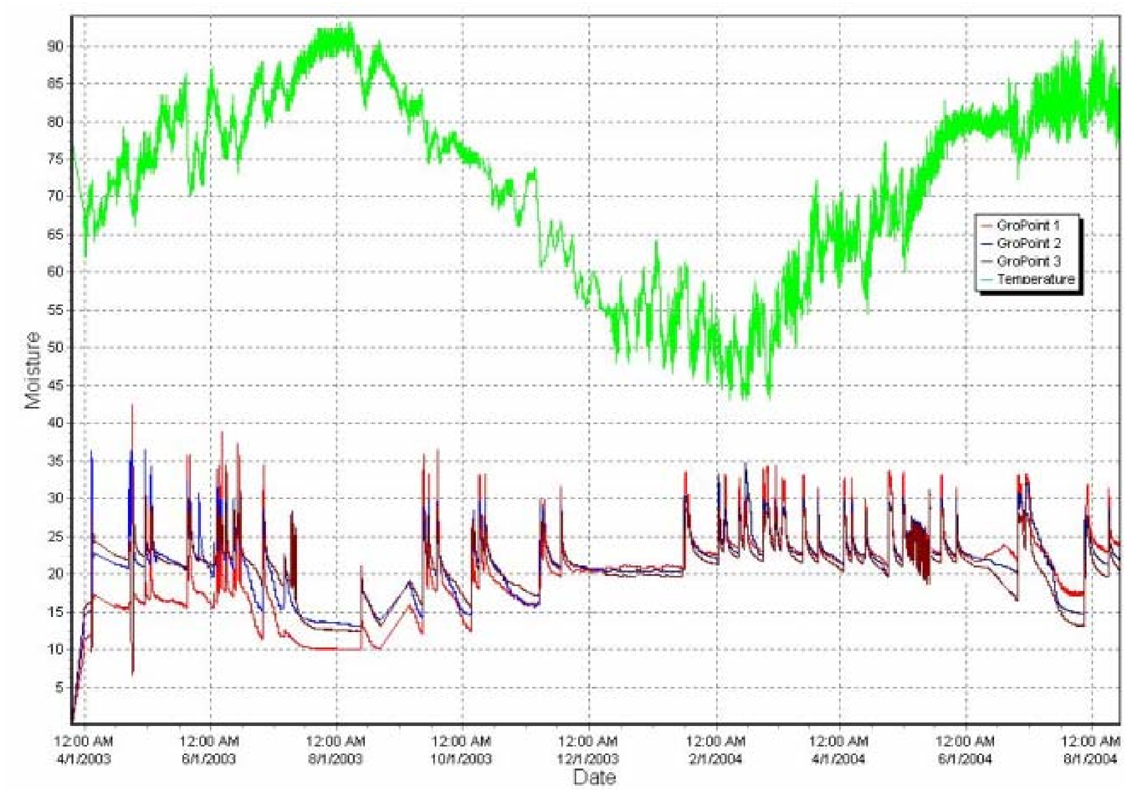



Figure 3.5: Volumetric moisture and temperature data (PLOT 1)

The temperature readings clearly show the day and night temperature variations as well as seasonal temperature variations. It is interesting to note that the maximum temperature recorded during the monitoring is around 100º F and the minimum temperature recorded is around 45º F. These values are consistent with those expected in buried conditions near the surface. The moisture readings measured by Gropoint sensors also reflect the moisture variation trends expected at various depths. Note that the Gropoint 2 moisture sensor denotes readings at the shallow depth (6 in.) and Gropoint 3 moisture sensor identifies with moisture readings at the deep depth (18 in.). As expected, the moisture fluctuations from the shallow depth sensor are higher than those at the other 2 depths, explaining that the near surface depth is susceptible to seasonal temperature variations. Both moisture and temperature fluctuations are continuously monitored and this data was analyzed to assess the encapsulation effects. Test data collected from all the test and Control Plots are included in Appendix A.

### 3.3.2 Erosion Analysis

Topographic surveys were periodically conducted during moisture and temperature data collection and these results were used to evaluate vertical movements (swell/shrinkage) of the encapsulated surface and any grading (elevational) changes in both the longitudinal and transverse directions. A Total Station survey instrument was used to measure the elevation of each spot in each test plot which was marked by a spike. Each plot had 5 spikes set in both the longitudinal and transverse directions as shown in Figure 3.6. The distance from the spikes in the longitudinal direction was 10 feet. Depending on the width of the test plot, the distance from spikes 4 to 2 and spikes 2 to 5 were set at 2 and 4 feet for the 5 foot and the 10 foot wide test plots respectively. Typical surveying data collected from the survey is presented in Table 3.2.

The vertical displacements were calculated by subtracting the elevation of each spike by an initial elevation, which was established at the beginning of the monitoring process immediately after the test plot construction in April, 2003. For example, the elevation of spike 3 on June 1, 2003 would be equal to -9.79-(-9.75) or -0.04 ft. This implies that the surface of the test plot has been eroded by an amount of 0.04 feet. A total of 19 sets of readings were taken during the duration of the project.

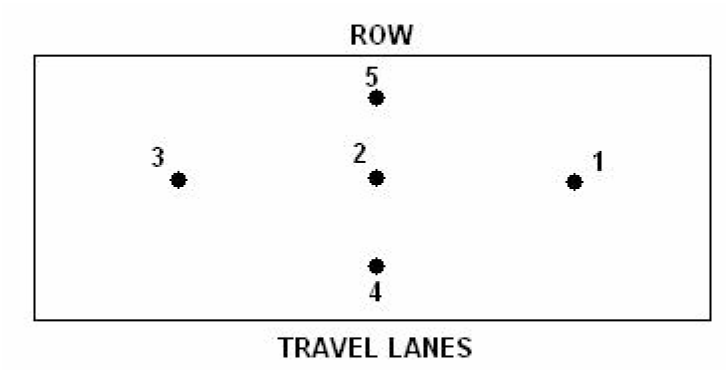



Figure 3.6: Typical section showing spike orientation

Table 3.2: Typical surveying data from test plot 1

| Date | Station 1 (BSC) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Apr 3 03 | -9.65 | -9.74 | -9.75 | -9.18 | -10.42 |
| Apr 15 03 | -9.54 | -9.69 | -9.68 | -9.12 | -10.35 |
| Apr 24 03 | -9.59 | -9.7 | -9.73 | -9.2 | -10.39 |
| Jun 01 03 | -9.65 | -9.82 | -9.79 | -9.23 | -10.44 |
| Jun 16 03 | -9.63 | -9.76 | -9.77 | -9.22 | -10.51 |

Potential elevation changes of each plot were calculated using the average readings of all stations and these results were used in the analysis to address erodability of the CMTs during service.

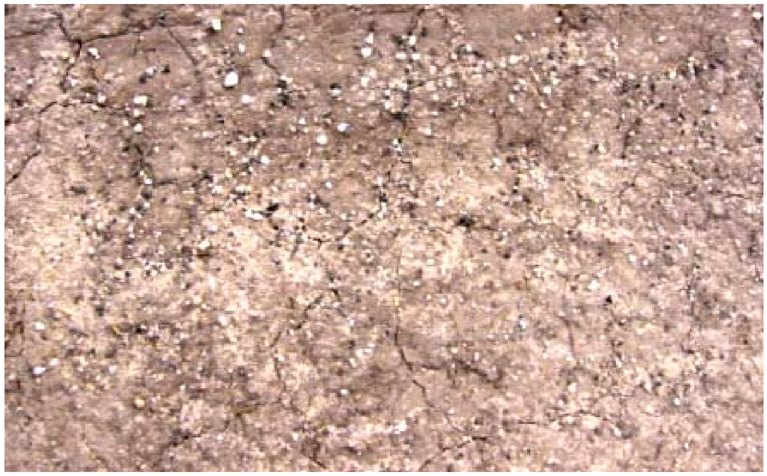
### 3.3.3 Shrinkage analysis

Though free swell analysis strain tests are often used in geotechnical practice to characterize expansive soils, shrinkage or desiccation strains are considered equally important since they initiate the failure mechanisms (cracks) in expansive soils to expose large volumes of soil surface area at varying depths to saturation. If not immediately remediated, shrinkage strains in soils induced by dry environments can lead to crack propagation in both the lateral and longitudinal directions. As a result, large volumes of expansive subgrades near shrinkage cracks will have moisture access during rainy seasons and will start expanding once they are saturated. Hence, it is essential to properly characterize the shrinkage strain potentials of natural and compost amended soils.

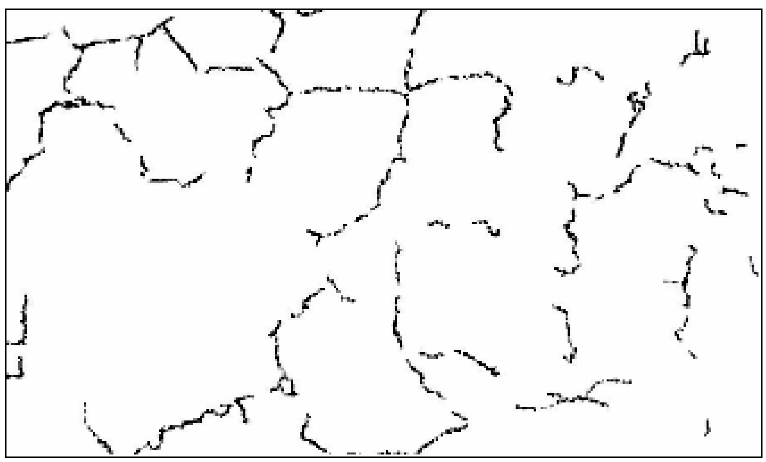
Typical shrinkage strain characterization practice is to collect soil samples and then subject them to either linear or volumetric shrinkage strain tests. These laboratory tests were not preferred in this research since the materials to be tested would be small in size and the tests would not provide any understanding of longitudinal and shrinkage strains observed in the field. This method would also lead to manual errors in the measurement of linear shrinkage strain magnitudes of soils. To rectify this error, a new digital image processing technique developed by UTA was employed.

***Digital Image Analysis***

Imaging software which was developed by Scion Corporation was adopted to analyze the shrinkage cracks. The primary image processing technique used in the research work was “thresholding”. The purpose of “thresholding” is to select the pixel intensity value which separates the objects from a general background. Ideally, after “thresholding”, all cracked portions would be depicted as black pixels and soil as white pixels as shown in Figure 3.7 a and b.



(a)



(b)

Figure 3.7: Digital images (a) before (b) after the analysis

***Shrinkage Calculation***

The following steps describe the percent shrinkage of the test plots during the field data monitoring.

- The surface of each test plot was photographed with a high-resolution digital camera with the pictures then downloaded into a computer.

- The photograph was opened in Paint software and saved in a .bmp format.
- The soil picture was opened in the Scion image and the total area "$A_t$" of the entire sample was calculated using the "Measure" function of the Scion image software.
- A "threshold" value was selected to view the cracked and non-cracked portions. Once the non-cracked portions had been removed, the area of the cracked portion "$A_s$" was measured by using the "Measure" function in the Scion image software.
- Shrinkage was then calculated by taking the ratio or percentage of the "threshold" image in pixels ($A_s$) to the total area of the image in pixels ($A_t$).

$$\text{Shrinkage} = \frac{A_s}{A_t}$$

Due to the size of each test plot, several pictures were taken to cover the entire test surface area during each site visit. Three images were randomly taken for each test plot and shrinkage results of these three images were calculated and then used to determine the average shrinkage value of the test plot. These digital photos were taken during site visits on days during which no rain was recorded at the site in the past week. If rain events took place, the cracks were healed and the digital shrinkage strains would be lower. This would affect the overall statistical analysis and hence care was taken to collect the data that was representative of the shrinkage or dry conditions. The data collection and analysis of all test plots was continued for a total of seventeen months.

### 3.3.4 Paved shoulder cracking

In order to distinguish between the new and old cracks on the adjoining pavement, digital pictures of the paved shoulder were periodically taken. Old cracks had been crack sealed with a bitumen product and these can be seen in a digital photograph shown in Figure 3.8. As the paved shoulder began to deteriorate, cracks would continue to appear and propagate as well as widen. These cracks were recorded. By comparing the photographs at the same location, the severity of cracking could be estimated. Figure 3.8 presents both new and old cracks that appeared on the paved shoulder.

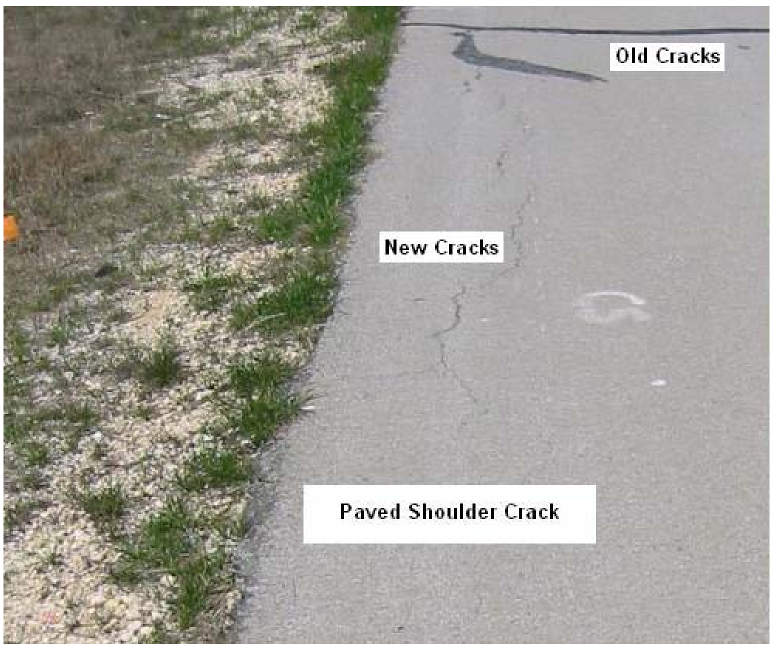



Figure 3.8: Paved shoulder cracks on the Control Plot

### 3.3.5 Vegetation Growth

Regardless of the use of composts to amend and protect unpaved shoulders and slopes, one of the eventual goals of this amendment is to allow native vegetation to grow naturally and permanently stabilize the soils in shoulders and slopes (Tyler, 2003).

In this research, an attempt was made to qualitatively assess the vegetation density in the test plots.

A digital photographic record showing the thickness of vegetation at each plot was collected and documented. A visual observation was used to compare vegetation cover and thickness at a specified plot or between several areas of each plot. These records were taken periodically. Figure 3.9 shows a typical record of vegetation growth at test plot 16.


Figure 3.9: Vegetation growth at each test plot

### 3.3.6 Environmental assessments

Several studies reported technical information on compost applications in land reclamation, erosion control, slope stabilization, and landscaping. None of these studies, however, reported on the quality and pollution loads of surface runoff emanated from compost treated areas nor its impact upon the water quality of the natural systems. This research focused on collecting runoff samples from three test plots. These samples were subjected to several environmental tests to determine the quality of surface runoff. Full details of this task can be found in (Qasim et al. 2004).

## 3.4 Summary

This chapter summarizes various field monitoring tasks used in this research to evaluate compost amended soils to serve as unpaved shoulder cover soils. Field instrumentation with moisture and temperature probes were used to collect moisture and temperature fluctuations during the monitoring period. Elevation surveys to address erosion and digital image analyses to evaluate shrinkage cracking of the test plots were discussed.

# CHAPTER 4
# ENVIRONMENTAL ASSESSMENTS ON RUNOFF QUALITY FROM CMT AND CONTROL PLOTS

## 4.1 Introduction

In this chapter, the extensive environmental quality assessments made on runoff samples collected from the three test plots are presented. These results are also compared with a few local studies conducted on highway runoff samples and EPA benchmark values. Possible causes of concentration levels of chemical contaminants in the present samples are explained along with the need for long term monitoring studies.

## 4.2 Location of Sampling Point

The sampling point for runoff from Biosolids Compost was located in CMT3-5-4, Plot 14, which was comprised of 20% Biosolids Compost mixed with native soil. The sampling point for runoff from Dairy Manure Compost was located in CMT1-5-4, Plot 16, which was comprised of 75% Dairy Manure Compost mixed with native soil. Surface runoff from the untreated soil was collected from the Control Plot.

## 4.3 Method of Sampling

The surface runoff was collected in 5 gallon buckets buried in the ground on the downside of the surface slope (Figure 4.1). A mound of soil was constructed on the backside to facilitate the collection of surface runoff into the buckets. Samples were withdrawn from each bucket by means of a small plastic bottle. After the samples were collected, the buckets were emptied. Samples were collected two times in a month. During this period, if rainfall occurred, the water sample was collected in the bucket and remained there until picked up on the next sampling day. The sampling and data collection was conducted over a period of several months (June 2003 – August 2004).

Figure 4.1 Collection of surface runoff samples using 5 gallon buckets

## 4.4 Analytical Work

A number of routine physical and chemical tests were performed on each sample to determine its quality. The analytical methods used followed the procedures outlined by the Standard Methods (1992). The physical and chemical tests conducted on each sample and analytical methods utilized are provided in Table 4.1.

Table 4.1: Routine physical and chemical tests and analytical methods used for each sample

| Parameters | Analytical Method |
|---|---|
| pH | Std. Methods 4500-$H^+$ B (pH meter) |
| Turbidity | Std. Methods 2130 B (Turbidimeter) |
| Total Suspended Solids (TSS) | Std. Methods 2540 D |
| Volatile Suspended Solids (VSS) | Std. Methods 2540 E |
| Total Dissolved Solids (TDS) | Std. Methods 2540 C |
| Volatile Dissolved Solids (VDS) | Std. Methods 2540E |
| Biochemical Oxygen Demand ($BOD_5$) | Std. Methods 5210 B |
| Chemical Oxygen Demand (COD) | Bioscience Inc. (Hach COD Reactor, 20 – 900 mg /L Std. Range Twist Cap Vials) |
| Total Kjeldahl Nitrogen (TKN) | Std. Methods 4500 N |
| Phosphorus | Std. Methods 4500-P D |
| Tannin and Lignin | Hach method |

## 4.5 Sample Preparation

The samples were collected in three liter plastic bottles and were brought to the laboratory within a time period of two hours. The samples were refrigerated to preserve the quality. Prior to conducting various tests, the appropriate amount of sample volume was taken out of the refrigerator and allowed to reach ambient lab temperature 70 $^oF$

(21°C). Two replicates of each test were conducted on each sample for accuracy and precision of the results. The average values of two replicates were reported.

## 4.6 Significance of Measured Parameters

The significance of the routine physical and chemical tests used in this investigation as they relate to the quality of surface runoff are briefly presented below (Standard Methods for Examination of Water and Wastewater, 18th Edition, 1992, Metcalf and Eddy, 2003).

***pH* -** Measurement of pH is one of the most important and frequently used tests in water chemistry. Practically every phase of water supply and wastewater treatment such as acid-base neutrality, water softening, precipitation, coagulation, disinfection and corrosion control are pH dependent. pH is a measure of acidity, alkalinity or neutrality of the water samples. The pH suitable for existence of most biological life is typically in the range of 6 to 9. Natural waters are slightly basic because of the presence of the natural bicarbonate and carbonates in soils.

***Turbidity* -** The clarity of a natural body of water is important for the aesthetic quality and for the productivity of the aquatic system. Turbidity gives an idea of suspended and colloidal matter in a water sample. High turbidity values are due to the presence of clay, silt, silica, organic detritus and micro-organisms. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted through the sample. The relationship between the turbidity and the concentration of suspended matter is difficult to determine because size, shape and refractive index of particulates also affect light scattering properties of a suspension. Nephelometric turbidity unit (NTU) is the common unit to express the turbidity.

***Solids*** **-** Solids refer to matter suspended or dissolved in water. Total suspended solids (TSS) are the solids retained over a 1.5 μm filter paper. Solids passing through 1.5 μm filter paper are known as dissolved solids. Suspended solids eventually settle to the bottom of the natural body of water, causing formation of a sludge blanket. This may change the bottom condition affecting the growth and development of benthic organisms. Total dissolved solids (TDS) can change the salinity of water. Volatile suspended solids (VSS) and volatile dissolved solids (VDS) are determined by igniting the sample in a muffle furnace at 550°C. Volatile solids (VS) signify the amount of organic matter present in the sample.

***Biochemical Oxygen Demand*** **(*BOD*) -** BOD is defined as the amount of oxygen required by micro-organisms to stabilize decomposable organic matter under aerobic conditions. The standard BOD test is conducted over a 5-day period at 20ºC. The $BOD_5$ test is useful in determining the extent of organic pollution in natural waters. Clean waters have $BOD_5$ of less than one (1) mg/L. Medium to strongly polluted waters have $BOD_5$ of 1-3 and above 3 mg/L, respectively.

***Chemical Oxygen Demand*** **(*COD*) -** The chemical oxygen demand (COD) test is used to measure the oxygen equivalent of organic matter that can be oxidized by a strong oxidizing agent. COD is usually used as a substitute test for $BOD_5$ as it can be conducted in less than three hours. The organic matter discharged in natural waters will exert an oxygen demand. This will cause the depletion of dissolved oxygen in the receiving body of water. A low level of dissolved oxygen is a serious threat to aquatic life and the aesthetic quality of water. The ratio of $COD/BOD_5$ is important to determine the biodegradability of organic matter. A higher ratio indicates a higher proportion of non-biodegradable organic fraction. For example, fresh municipal wastewater has a $COD/BOD_5$ ratio of 2-3. Secondary effluent has a ratio of 6-10.

Drainage from compost treated sites may result in higher amounts of organic matter and hence this ratio test is considered to evaluate the presence of organic matter in the run off samples collected from the CMT plots.

***Total Kjeldahl Nitrogen* (*TKN*) –** Organic, ammonia, nitrite and nitrate nitrogen are the various forms of nitrogen found in waters and wastewaters. Ammonia nitrogen is released by bacterial action on compounds containing organically bound nitrogen. These compounds are proteins and amino acids, nucleic acids and urea, and numerous synthetic organic materials. Total Kjeldahl Nitrogen is a measure of organic plus ammonia nitrogen. Composted materials contain higher amounts of nitrogenous compounds, which may cause higher concentrations of ammonia and organic nitrogen in the streams. Ammonia nitrogen and organic nitrogen are unstable forms, and would cause oxygen demand for oxidation into nitrite and then to nitrate, which is the stable form of nitrogen. Nitrogen is also a nutrient responsible for eutrophication. Eutrophication may lead to algal blooms, depressed oxygen levels, odors and release of toxins.

***Total Phosphorus* (*TP*) -** Phosphorus is a growth enhancing nutrient. Orthophosphates applied to agricultural or residential cultivated land as fertilizers are carried into surface waters with storm runoff. Organic phosphates are formed primarily by biological processes. Composted materials, especially Dairy Manure Compost, are a rich source of phosphorus. The presence of phosphorus in natural waters is an indication of potential for eutrophication.

***Tannin and Lignin* -** Lignin is the plant constituent that is often discharged as a waste during the manufacture of paper pulp. Lignin is a group of chemical compounds present in the cell walls of plants needed to create wood. Tannin is another plant constituent. Both tannin and lignin may enter the water supply through the degradation of plant residues, or through wastes from the tanning industry. The presence of tannin and lignin in natural waters is an indication of drainage from decayed wooded areas. Decayed wood matter is a source of natural organic matter in the receiving streams.

## 4.7 Test Results and Discussion

A total of 12 surface runoff samples from each of the Biosolids Compost (BSC), Dairy Manure Compost (DMC), and Control Soil (CS) plots were analyzed over a period of several months to determine their quality and pollutional strength. The water quality parameters analyzed were: (1) turbidity, (2) pH, (3) total suspended solids, (4) volatile suspended solids, (5) total dissolved solids, (6) volatile dissolved solids, (7) tannin-lignin, (8) phosphorus, (9) biochemical oxygen demand, (10) chemical oxygen demand, and (11) total kjeldahl nitrogen.

The average values of different water quality parameters in surface runoff from the Control Soil (CS), Biosolids Compost (BSC), and Dairy Manure Compost (DMC) are summarized in Table 4.2. The average values of these parameters for CS, BSC and DMC samples are plotted in Figures 4.2 to 4.12.

Table 4.2: Average concentrations of different water quality parameters

| **Parameters** | **CS** | **BSC** | **DMC** |
|---|---|---|---|
| Turbidity (NTU) | 35.6 | 21.2 | 53.4 |
| pH | 7.1 | 7.6 | 7.6 |
| Total Suspended Solids (TSS),mg/L | 26 | 28 | 57 |
| Volatile Suspended Solids (VSS),mg/L | 12 | 16 | 30 |
| Total Dissolved Solids (TDS),mg/L | 197 | 737 | 1068 |
| Volatile Dissolved Solids (VDS),mg/L | 29 | 125 | 201 |
| Tannin-Lignin, mg/L | 2.9 | 5.5 | 13.2 |
| Phosphorus, mg/L | 0.4 | 1.9 | 3.0 |
| BOD, mg/L | 6.1 | 7.7 | 18.9 |
| COD, mg/L | 57 | 256 | 387 |
| TKN, mg/L | 1.3 | 4.8 | 10.4 |

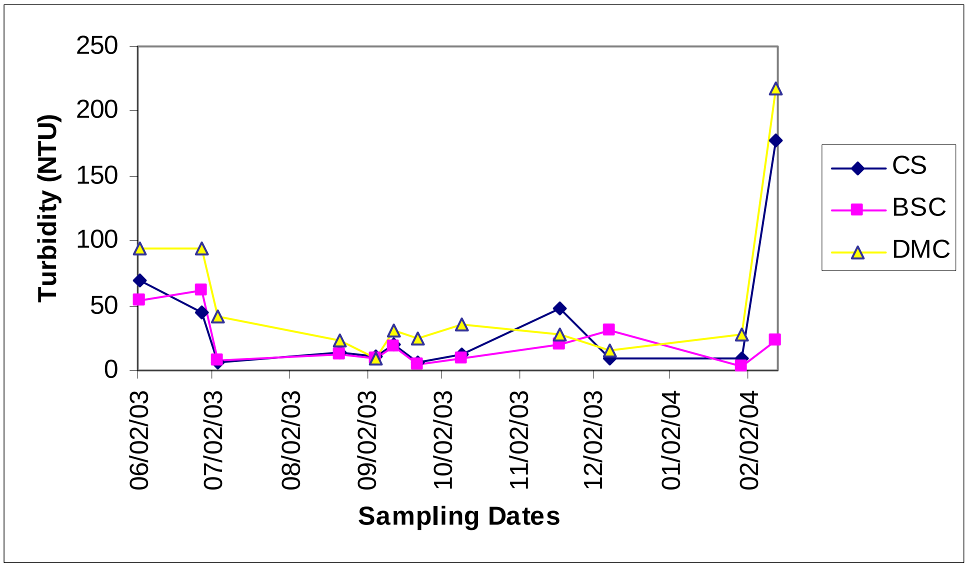



Figure 4.2 Turbidity values in surface runoff

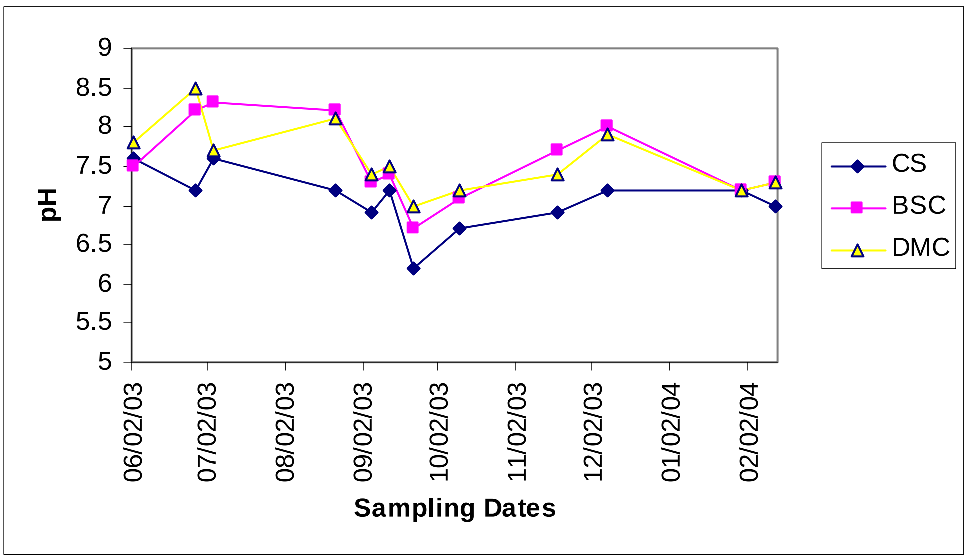



Figure 4.3: pH values in surface runoff

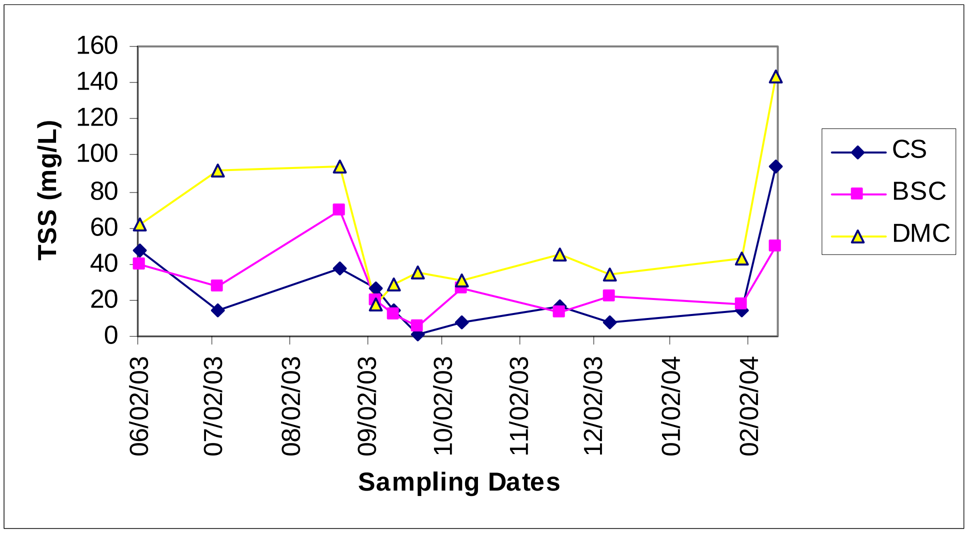



Figure 4.4: Total Suspended Solids (TSS) values in surface runoff

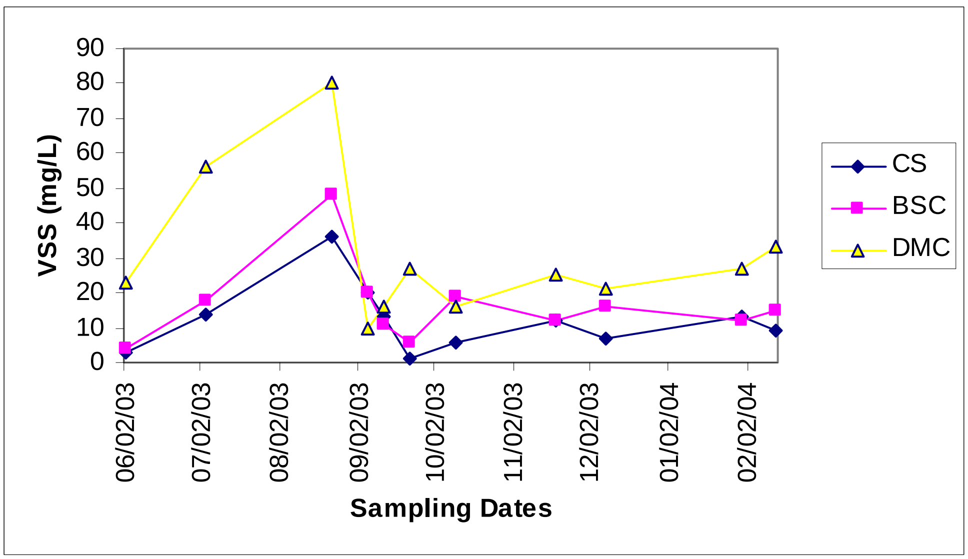



Figure 4.5: Volatile Suspended Solids (VSS) values in surface runoff

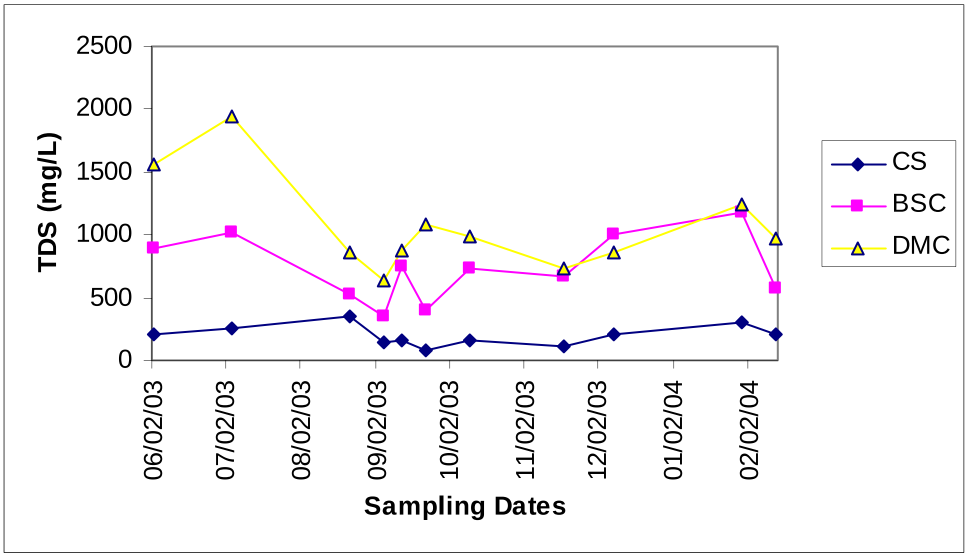



Figure 4.6: Total Dissolved Solids (TDS) values in surface runoff

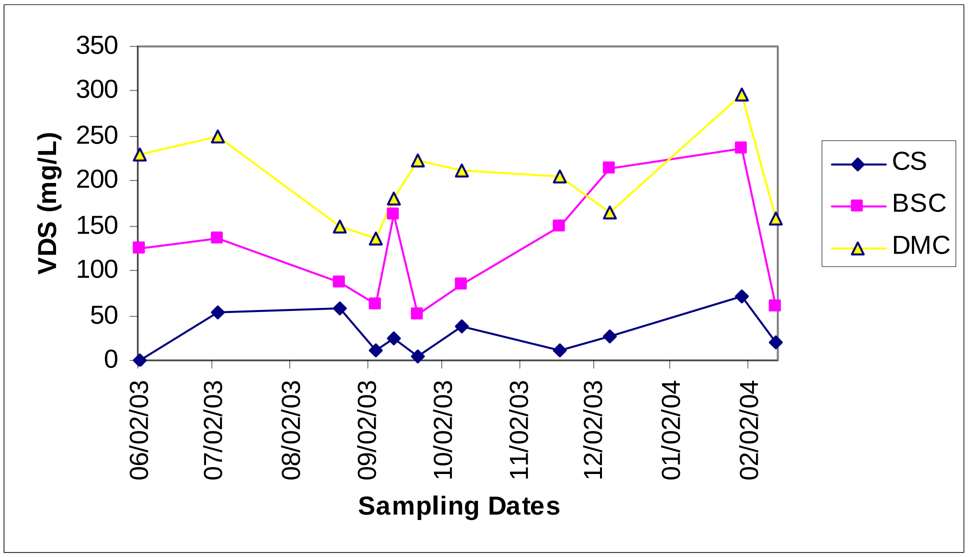



Figure 4.7: Volatile Dissolved Solids (VDS) values in surface runoff

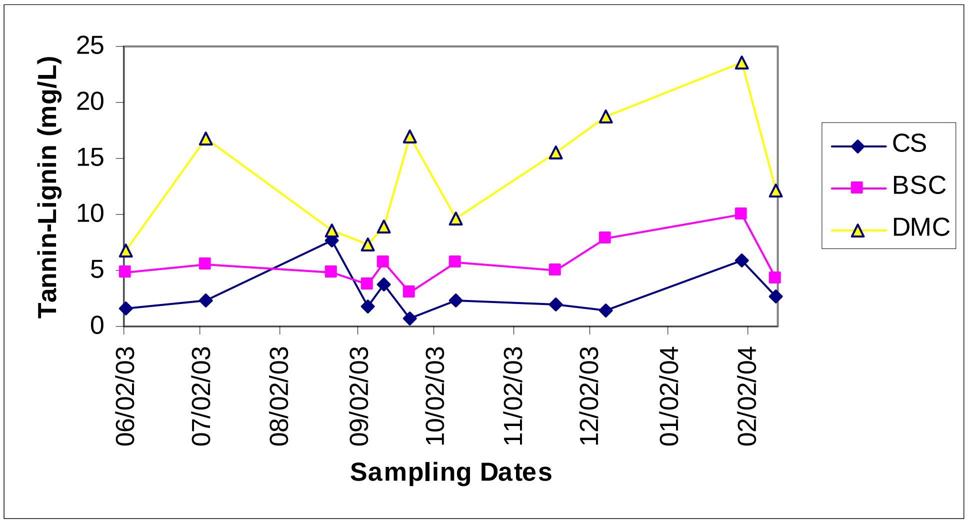



Figure 4.8: Tannin and Lignin values in surface runoff

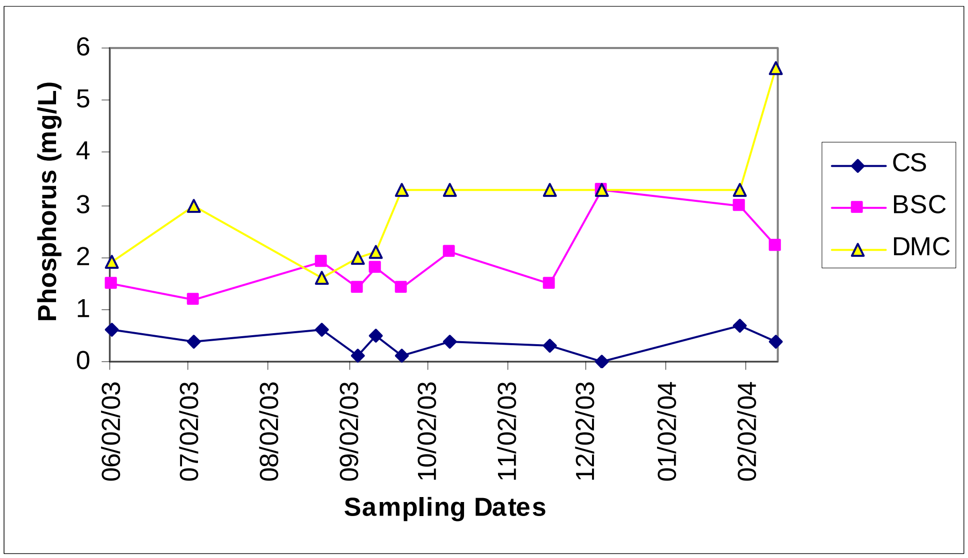



Figure 4.9: Phosphorus values in surface runoff

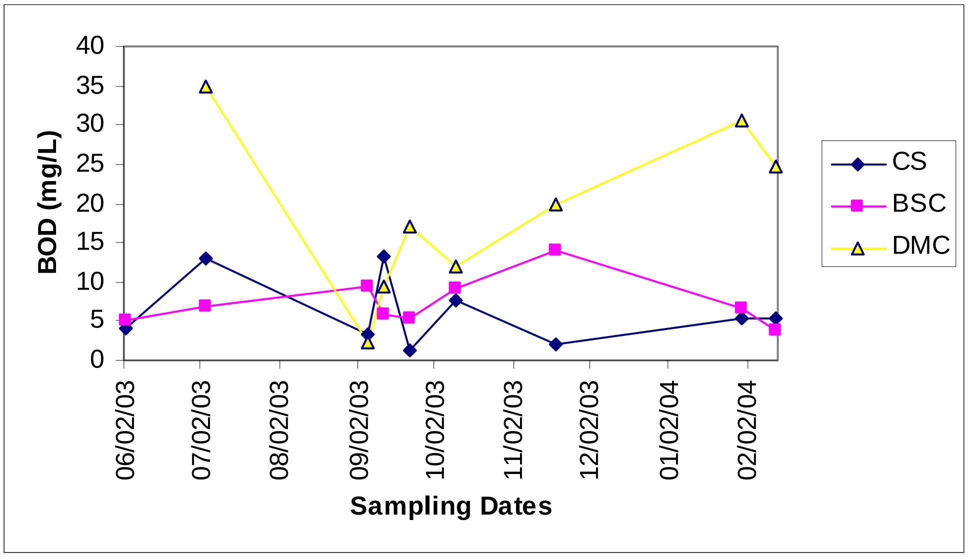



Figure 4.10: Biochemical Oxygen Demand (BOD) values in surface runoff

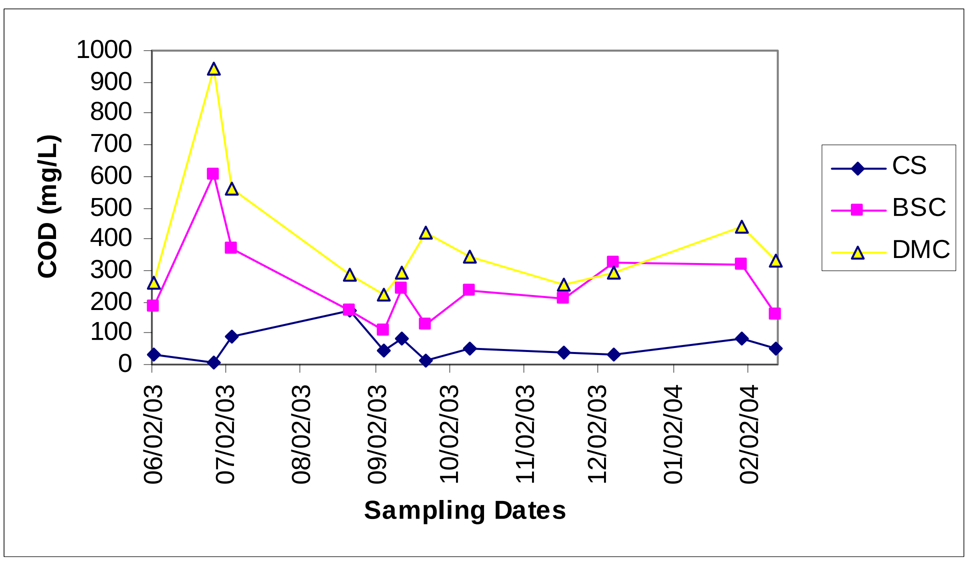



Figure 4.11: Chemical Oxygen Demand (COD) values in surface runoff

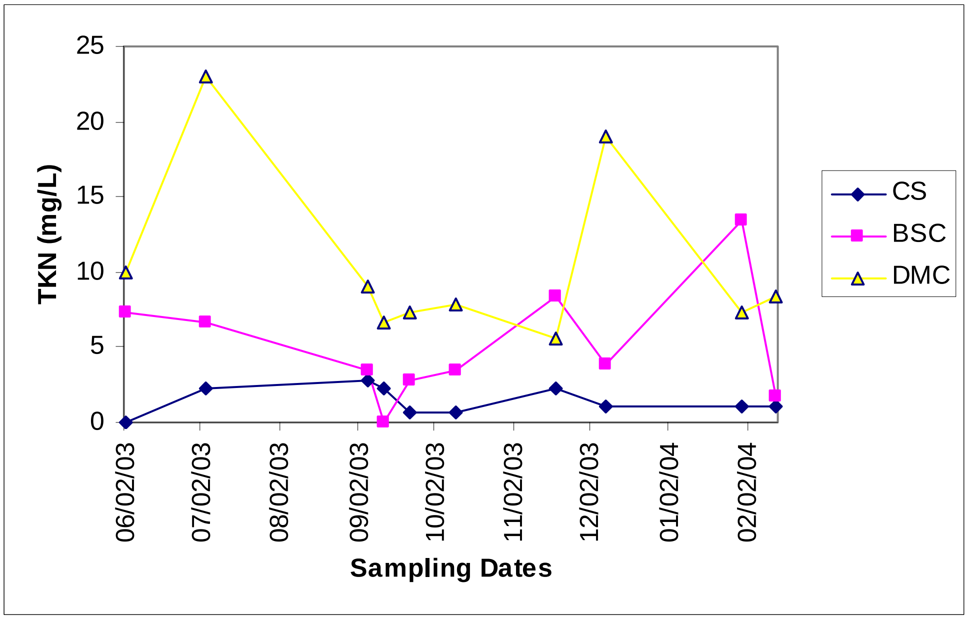



Figure 4.12: Total Kjeldahl Nitrogen (TKN) values in surface runoff

In the pollution control field, the washout effect or time-dependent decay of the source is necessary to establish its long-term impact upon the environmental quality. To establish this trend, the time-dependent concentration profiles of various parameters in surface runoff samples from the CS, BSC and DMC sites are plotted in Figures 4.2-4.12. The X-axis in these plots is the time scale on which each data point corresponds to the sampling dates.

The concentration profiles do not clearly indicate the decreasing trends with time. Because of only short-time sampling periods, the concentration profile cannot be truly established. A number of mathematical models are available in the literature that can be applied to establish the time-dependent prediction of the concentrations of various pollutants in the surface runoff. Additional data such as rain-gauge readings, drainage area, maximum leachable concentration in the source, and others may be needed.

A comparison of surface runoff quality in terms of all measured parameters from three test sites was made using the student *t*-test. The student *t*-test is normally used for statistical comparison of two means to determine whether or not they are the same. The test is commonly used for comparative evaluation of the performance of two processes; equipment, chemicals, or analytical laboratory results. The null hypothesis states that the means of the two samples are equal. The null hypothesis is true only when the calculated absolute value of *t* is less than the Tabled critical two-tailed value at the 95 % confidence level. In this investigation the student *t*-test is conducted between the concentrations of various pollutants in surface runoff from (1) CS and BSC study areas and (2) CS and DMC study areas. The results of these comparisons are provided below.

### *4.7.1 Comparison of Surface Runoff Quality from the CS and BSC Areas*

The calculated student *t* values, and critical *t* values at 95 % confidence level and comments are summarized in Table 4.3. It may be noted that the concentration of most of the key constituents are higher for the BSC samples than those of the CS samples.

### *4.7.2 Comparison of Surface Runoff Quality from the CS and DMC Areas*

The results of the student *t*-test for the CS and DMC data are summarized in Table 4.4. The concentrations of most of the constituents in surface runoff from the DMC are significantly higher than those in the CS.

Table 4.3: Results of student *t*-test on various contaminants in surface runoff from the Control Soil (CS) and Biosolids Compost (BSC) study areas

| **Parameter** | **Calculated *t* Value** | **Critical *t* Value at 95% Confidence Level** | **Null Hypothesis** | **Comments** |
|---|---|---|---|---|
| Turbidity (NTU) | 0.95 | 2.07 | Same | |
| pH | 2.72 | 2.07 | Different | BSC value is higher than CS value |
| Total Suspended Solids (TSS),mg/L | 0.22 | 2.09 | Same | |
| Volatile Suspended Solids (VSS),mg/L | 0.94 | 2.09 | Same | |
| Total Dissolved Solids (TDS),mg/L | 6.43 | 2.09 | Different | BSC value is higher than CS value |
| Volatile Dissolved Solids (VDS),mg/L | 4.74 | 2.09 | Different | BSC value is higher than CS value |
| Tannin-Lignin, mg/L | 3.01 | 2.09 | Different | BSC value is higher than CS value |
| Phosphorus mg/L | 7.25 | 2.09 | Different | BSC value is higher than CS value |
| BOD mg/L | 0.68 | 2.12 | Same | |
| COD mg/L | 4.76 | 2.07 | Different | BSC value is higher than CS value |
| TKN, mg/L | 2.92 | 2.09 | Different | BSC value is higher than CS value |

Table 4.4 Results of student *t*-test on various contaminants in surface runoff from the Control Soil (CS) and Dairy Manure Compost (DMC) study areas

| **Parameter** | **Calculated *t* Value** | **Critical *t* Value at 95% Confidence Level** | **Null Hypothesis** | **Comments** |
|---|---|---|---|---|
| Turbidity (NTU) | 0.81 | 2.07 | Same | |
| pH | 3.02 | 2.07 | Different | DMC value is higher than CS value |
| Total Suspended Solids (TSS),mg/L | 2.24 | 2.09 | Different | DMC value is higher than CS value |
| Volatile Suspended Solids (VSS),mg/L | 2.68 | 2.09 | Different | DMC value is higher than CS value |
| Total Dissolved Solids (TDS),mg/L | 7.34 | 2.09 | Different | DMC value is higher than CS value |
| Volatile Dissolved Solids (VDS),mg/L | 10.59 | 2.09 | Different | DMC value is higher than CS value |
| Tannin-Lignin, mg/L | 5.79 | 2.09 | Different | DMC value is higher than CS value |
| Phosphorus mg/L | 7.67 | 2.09 | Different | DMC value is higher than CS value |
| BOD mg/L | 3.22 | 2.13 | Different | DMC value is higher than CS value |
| COD mg/L | 5.63 | 2.07 | Different | DMC value is higher than CS value |
| TKN, mg/L | 5.15 | 2.09 | Different | DMC value is higher than CS value |

### 4.7.3. Comparisons of the Concentrations of Key Constituents

The North Central Texas Council of Governments (NCTCOG) reported in three studies the concentration of many constituents from TxDOT sites in the Dallas and Fort Worth Districts. The values of key constituents from these studies are compared in Table 4.5 with those from the CS, BSC and DMC test sites.

Table 4.5 Comparison of key constituents in surface runoff from TxDOT sites and UTA study areas

| Constituents | NCTCOG Study Data | | | UTA Study Data | | |
|---|---|---|---|---|---|---|
| | 1993 Study | 1997-2000 Study | 2000-2001 Study | CS Data | BSC Data | DMC Data |
| Total Suspended Solids (TSS), mg/L | 100 | 167 | 268 | 26 | 28 | 57 |
| Total Dissolved Solids (TDS), mg/L | 241 | 270 | 453 | 197 | 737 | 1068 |
| Biochemical Oxygen Demand (BOD), mg/L | 6.8 | 7.4 | 7.7 | 6.1 | 7.7 | 18.9 |
| Chemical Oxygen Demand (COD), mg/L | 62 | 45 | 51 | 57 | 256 | 387 |
| Total Kjeldahl Nitrogen (TKN), mg/L | 1.5 | 2.4 | 1.8 | 1.3 | 4.8 | 10.4 |
| Total Phosphorus (TP), mg/L | 0.3 | 0.4 | 0.4 | 0.4 | 1.9 | 3.0 |

A comparison of the data indicates that the key constituents TDS, $BOD_5$, COD, TKN and TP concentrations in surface runoff from the CS are similar to those from TxDOT sites. The concentrations of these constituents from the BSC areas are moderately higher than those from TxDOT sites. The concentrations of these constituents from the DMC areas are significantly higher than those from TxDOT sites.

The US EPA has developed benchmark concentration values for NPDES storm water permits for industrial activities. These values are used to determine if a facility is successfully implementing the Storm Water Pollution Prevention Plan (SWPPP). The concentrations of key constituents in surface runoff from the CS, BSC and DMC sites are compared in Table 4.6 with those of US EPA benchmark values under NPDES storm water permit for industrial activities.

Table 4.6 Comparison of key constituents in surface runoff from UTA study areas with US EPA benchmark values

| **Constituents** | **US EPA Benchmark Values** | **UTA Study Areas** | | |
|---|---|---|---|---|
| | | **CS** | **BSC** | **DMC** |
| TSS, mg/L | 100 | 26 | 28 | 57 |
| $BOD_5$, mg/L | 30 | 6.1 | 7.4 | 19 |
| COD, mg/L | 120 | 57 | 256 | 387 |
| Ammonia-N, mg/L | 19 | - | - | - |
| TKN, mg/L | - | 1.3 | 4.8 | 10.4 |
| TP, mg/L | 2.0 | 0.4 | 1.9 | 3.0 |

A comparison of surface runoff concentrations from three test areas with US EPA benchmark values clearly indicates that with the exception of COD and TP the concentrations of all constituents from compost treated sites are within the US EPA benchmark values.

### 4.7.4 Probable Causes of High Concentrations of Contaminants

The concentrations of measured parameters in the surface runoff samples from the BSC and DMC applied sites were the highest values. Two factors may have contributed to this fact: (1) high proportions of compost in the test plots, and (2) location of sampling points and sampling procedure. Both of these factors are discussed below.

The compost manufactured topsoil over the test plots contained (a) 20 % BSC and 80 % CS by volume, and (b) 75 % DMC and 25 % CS by volume. These proportions of manures are probably higher than the optimum values needed to stop the desiccation cracking. If optimum proportions of compost in the manufactured topsoil to control the desiccation cracking were used in the test plots, then the concentration of pollutants in the surface runoff may be lower.

The sampling points were located at the edge of the compost manufactured topsoil. As a result, the surface runoff collected in the sampling buckets was totally from the manufactured topsoil without the benefit of any dilution effect. Also, these samples remained in the bucket for several days and became concentrated due to evaporation. In a real situation, the surface runoff from the manufactured topsoil will also contain the drainage from the natural ground until the mixture reaches the surface drains. The non-point sampling requirement is to collect the samples from the nearest surface drains. Therefore it is speculated that the surface runoff samples will have the benefit of dilution, and the concentration of contaminants would be lower.

## 4.8 Summary

Based upon the results of a comprehensive literature search on the quality of surface runoff from the TxDOT sites, US EPA benchmark values under NPDES permit program for non-point sources, and a sampling program from manufactured topsoil sites, the following observations are made.

The student *t*-test analysis clearly indicated that the surface runoff from compost manufactured topsoil contains higher concentrations of contaminants than those from the CS. Furthermore, the surface runoff from the DMC test plot has higher concentrations than that from the BSC test plot. Comparisons of surface runoff quality from compost manufactured topsoil with US EPA benchmark and NCTCOG measured values indicates that certain pollutant concentrations in surface runoff from compost manufactured topsoils were higher than the benchmark and NCTCOG measured values. These values were probably higher because of the high proportion of composts used in the manufactured topsoil, and due to sample collection points located immediately at the end of test plots. If the proportion of compost is lowered, and the sampling point is located in the surface drain, pollutant concentration in runoff will be lowered because of dilution effects.

The time dependent concentration profile curves indicate that there may be a slight decrease in concentration of contaminants in the surface runoff with respect to time. Long-term sampling data along with rainfall records, drainage area, leachate material in the manufactured topsoil, and other information are needed to utilize the predictive modeling.

# CHAPTER 5

# ANALYSIS OF FIELD PERFORMANCE TEST RESULTS

## 5.1 Introduction

This chapter addresses key questions regarding the field performance of compost-amended and local soils. The effectiveness of each CMT on the reduction of moisture and temperature variations, erosion control, desiccation cracking, paved shoulder cracking and vegetation reestablishment are discussed. The effects of treatment depth and width are also explained. Ranking analysis based on field performance was performed to determine the most efficient field application.

## 5.2 Methods of analysis

Methods of analysis used consisted of statistical analysis and visual observations. In most cases, questions are answered by statistical analyses using comparison tests such as the t- test. In the t-test, the mean values of performance indices for each CMT and the Control Plot are compared. A statistical program was used to perform all analyses in this research. All statistical differences among treatments identified in this research were set at a p-value of 0.05 or less. This means that there is less than a 5% chance that the treatment means are not truly different. Once significant differences in performance indices are found, then the effectiveness of compost amendments to mitigate shrinkage cracking can be explained. However, if the statistical analyses show no significant difference between the Control Plot and other CMT plots, then it can be mentioned that the CMTs and Control Plot showed similar performance. In such cases, the plot performance and compost enhancements is still evaluated by assessing the variations in magnitudes of average values of performance index parameters.

Visual observation was used to compare the performance of CMT plots when magnitudes of performance indices could not be determined. Both vegetation growth and appearance of new cracks on the paved shoulders came under this category. Digital photographic records were taken periodically at the same test locations to record the magnitudes of performance indices at each plot. These records were then compared with photos taken immediately after construction.

## 5.3 Analysis of field data

### 5.3.1 Moisture Fluctuations

Volumetric moisture contents and soil temperature were continuously recorded from April 2003 to August 2004. A typical example of the data is shown in Figure 5.1. The moisture variation was determined by finding the differences between maximum and minimum volumetric moisture contents in each month. Average values of these moisture variations are determined and used as the 'mean moisture variation' in this research. Moisture variation analysis was done by comparing the 'mean moisture variation' of every plot to the 'mean moisture variation' of the Control Plot.

Due to the hydrophilic nature of composts, it was anticipated that plots covered with compost amended topsoils would be able to attract and retain moisture and therefore reduce moisture variations. The moisture retention was expected to reduce the desiccation cracking in the subsoil and subsequentially through the pavement. However, from the moisture variation analysis, the moisture variation of the subgrade soils at the 6 inch depth does not vary significantly when compared with the moisture variation of the Control Plot. The results are shown in Table 5.1.

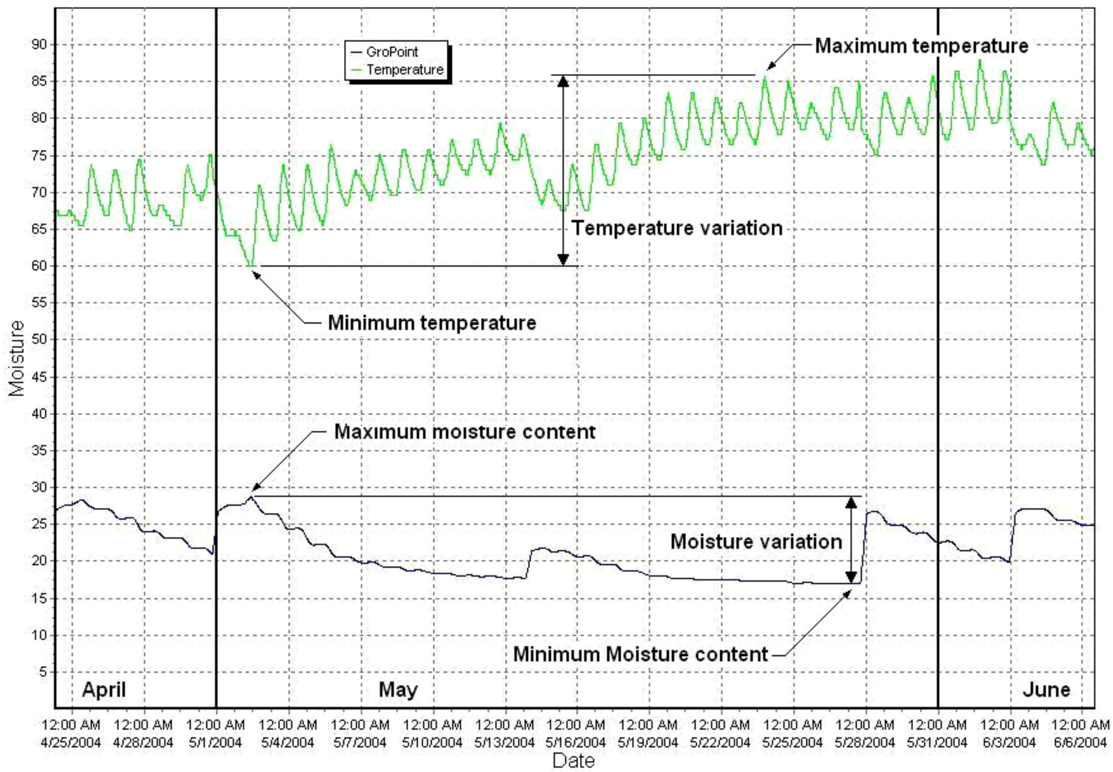



Figure 5.1: Typical temperature and volumetric moisture data

Table 5.1: Analysis on 'Mean Moisture Variations'

| **Plot** | **Control mean moisture variation** | **Plot mean moisture variation** | **t-value** | **Df** | **p-value 2-sided** | **Variation at 6 in depth** |
|---|---|---|---|---|---|---|
| CMT4-10-4 | 15.34 | 12.77 | 0.8384 | 26 | 0.4095 | Same |
| CMT3-10-4 | 15.34 | 13.78 | 0.5023 | 25 | 0.6198 | Same |
| CMT2-10-4 | 15.34 | 11.63 | 0.7412 | 19 | 0.4677 | Same |
| CMT1-10-4 | 15.34 | 21.84 | -1.7618 | 20 | 0.0934 | Same |
| CMT4-10-2 | 15.34 | 12.68 | 0.8314 | 24 | 0.4139 | Same |
| CMT3-10-2 | 15.34 | 15.13 | 0.0524 | 23 | 0.9587 | Same |
| CMT2-10-2 | 15.34 | 17.35 | -0.3930 | 24 | 0.6978 | Same |
| CMT1-10-2 | 15.34 | 22.19 | -1.6756 | 23 | 0.1074 | Same |
| CMT4-5-2 | 15.34 | 15.80 | -0.1333 | 23 | 0.8951 | Same |
| CMT3-5-2 | 15.34 | 13.06 | 0.5827 | 18 | 0.5673 | Same |
| CMT2-5-2 | 15.34 | 14.40 | 0.2436 | 23 | 0.8097 | Same |
| CMT1-5-2 | 15.34 | 15.05 | 0.0732 | 20 | 0.9424 | Same |
| CMT4-5-4 | 15.34 | 16.75 | -0.4580 | 24 | 0.6511 | Same |
| CMT3-5-4 | 15.34 | 18.43 | -0.8587 | 23 | 0.3993 | Same |
| CMT2-5-4 | 15.34 | 14.54 | 0.1921 | 21 | 0.8495 | Same |
| CMT1-5-4 | 15.34 | 18.15 | -0.5214 | 23 | 0.6071 | Same |

Although 'mean moisture content' variations are not statistically different, the CMTs' performance can be ranked by using the magnitudes of 'mean moisture variation' values recorded during the monitoring. Table 5.2 shows the 'mean moisture variations' of all plots from the lowest to the highest values. It can be noted that approximately half of all 16 plots have less variations than the Control Plot and the moisture variations in all plots varied from 11.6 to 22.2%. A high variability in moisture variations in certain plots is attributed to highly localized conditions such as percent compost, compost properties, soil properties, and vegetation density. Figure 5.2 presents results in graphical form.

Table 5.2: Sorted 'Mean Moisture Variations'

| Material | Compost | Width (ft) | Thickness (in.) | Mean Moisture Variation (%) |
|---|---|---|---|---|
| CMT 2 | DMC | 10 | 4 | 11.63 |
| CMT 4 | BSC | 10 | 2 | 12.68 |
| CMT 4 | BSC | 10 | 4 | 12.77 |
| CMT 3 | BSC | 5 | 2 | 13.06 |
| CMT 3 | BSC | 10 | 4 | 13.78 |
| CMT 2 | DMC | 5 | 2 | 14.40 |
| CMT 2 | DMC | 5 | 4 | 14.54 |
| CMT 1 | DMC | 5 | 2 | 15.05 |
| CMT 3 | BSC | 10 | 2 | 15.13 |
| CS | - | 10 | 4 | 15.34 |
| CMT 4 | BSC | 5 | 2 | 15.80 |
| CMT 4 | BSC | 5 | 4 | 16.75 |
| CMT 2 | DMC | 10 | 2 | 17.35 |
| CMT 1 | DMC | 5 | 4 | 18.15 |
| CMT 3 | BSC | 5 | 4 | 18.43 |
| CMT 1 | DMC | 10 | 4 | 21.84 |
| CMT 1 | DMC | 10 | 2 | 22.19 |

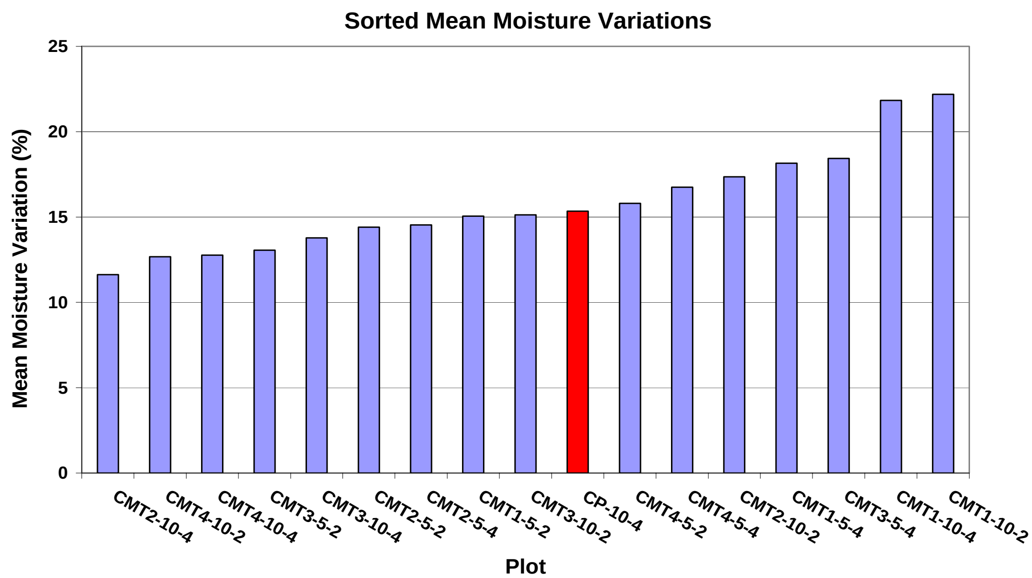



Figure 5.2: Sorted 'Mean Moisture Variations' values of present plots

The following observations can be listed from the results reported in Table 5.2 and Figure 5.2.

- Biosolids Compost amended soils provided effective encapsulation when they were used to cover the test plots by 10 ft wide and 4 in. deep.
- Dairy Manure Composts also provided some encapsulation, when they were used without any amendments (CMT 2).
- Dairy Manure Compost amendments (CMT 1) did not appreciably preserve the moisture content in the plots, which are attributed to low amounts of organics present in these amendments.

Another type of analysis was attempted by assessing the moisture variations in the test plots with respect to initial moisture contents. Table 5.3 and Figure 5.3 compare the initial moisture content in each plot with an average low or minimum moisture content. As mentioned earlier, most compost plots, except plots 3, 8, 15 and 16, did not experience any moisture losses beyond their initial compaction moisture contents. The Control Plot (17) with no compost covers experienced loss in moisture content below the initial compaction moisture content. The plots that experienced the most moisture losses were some of the Dairy Manure Compost plots indicating that this material possibly did not provide effective encapsulation of the surface. In the case of the Biosolids Compost plots, the reduction of the CMT treatment width appeared to result in higher moisture variations.

Table 5.3: Moisture content comparisons in control and test plots

| Plot | Plot No. | Min. Moisture Readings @ 6 in. | Initial Moisture Readings @ 6 in. |
|---|---|---|---|
| CMT4-10-4 | 1 | 17.59 | 14.31 |
| CMT3-10-4 | 2 | 15.99 | 12.55 |
| CMT2-10-4 | 3 | 7.12 | 22.55 |
| CMT1-10-4 | 4 | 13.12 | 10.00 |
| CMT4-10-2 | 5 | 16.81 | 12.35 |
| CMT3-10-2 | 6 | 17.04 | 12.94 |
| CMT2-10-2 | 7 | 19.47 | 17.45 |
| CMT1-10-2 | 8 | 11.58 | 13.14 |
| CMT4-5-2 | 9 | 20.26 | 11.96 |
| CMT3-5-2 | 10 | 18.46 | 14.12 |
| CMT2-5-2 | 11 | 15.00 | 11.76 |
| CMT1-5-2 | 12 | 14.84 | 11.37 |
| CMT4-5-4 | 13 | 16.03 | 12.35 |
| CMT3-5-4 | 14 | 14.95 | 13.92 |
| CMT2-5-4 | 15 | 16.04 | 18.04 |
| CMT1-5-4 | 16 | 14.36 | 19.61 |
| CP-10-4 | 17 | 12.66 | 16.86 |

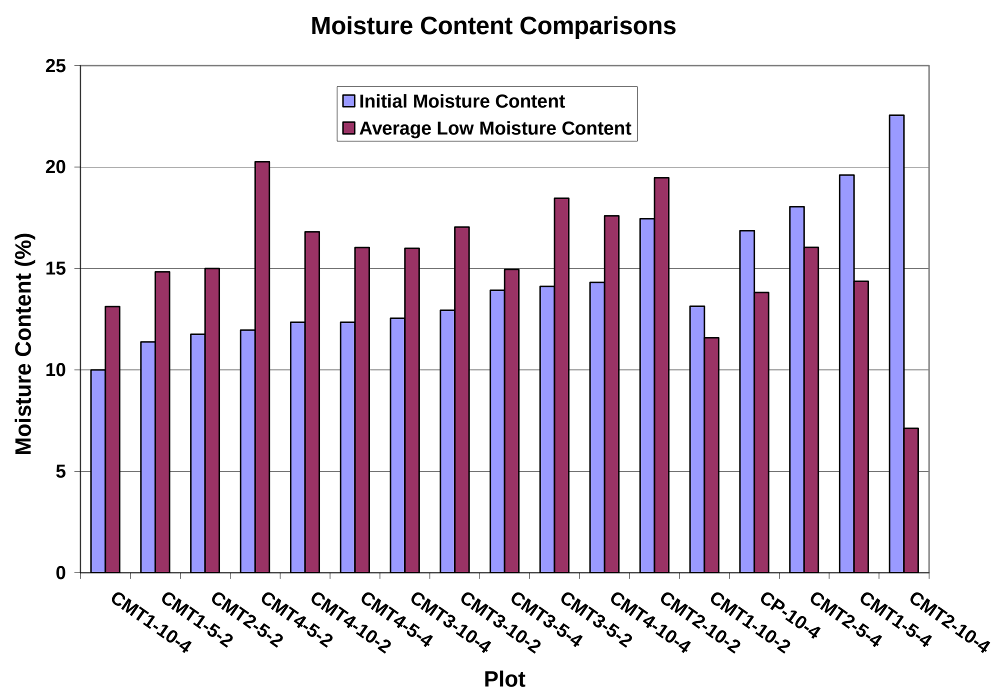



Figure 5.3: Moisture content comparisons

### 5.3.2 Temperature Fluctuations

Temperature variation analysis was also performed in a similar manner as moisture variation analysis. In Table 5.4, most temperature variations except on plots (CMT4-10-4 and CMT2-10-4) are not statistically different. Therefore, the CMT performance was ranked by using the average values.

Table 5.4: Temperature variation analysis

| Plot name | CP Mean | Plot Mean | t-value | df | p-value 2-sided | Variation at 6 in. depth |
|---|---|---|---|---|---|---|
| CMT4-10-4 | 22.71 | 15.57 | 3.2770 | 14 | 0.0055 | Less |
| CMT3-10-4 | 22.71 | 15.60 | 2.0687 | 14 | 0.0576 | Same |
| CMT2-10-4 | 22.71 | 15.18 | 2.2352 | 11 | 0.0471 | Less |
| CMT1-10-4 | 22.71 | 17.00 | 1.7986 | 13 | 0.0953 | Same |
| CMT4-10-2 | 22.71 | 19.56 | 1.3365 | 14 | 0.2027 | Same |
| CMT3-10-2 | 22.71 | 18.26 | 1.7451 | 14 | 0.1029 | Same |
| CMT2-10-2 | 22.71 | 21.43 | 0.5169 | 14 | 0.6133 | Same |
| CMT1-10-2 | 22.71 | 30.29 | -2.1326 | 10 | 0.0588 | Same |
| CMT4-5-2 | 22.71 | 24.88 | -0.5225 | 14 | 0.6095 | Same |
| CMT3-5-2 | 22.71 | 20.75 | 0.6540 | 11 | 0.5265 | Same |
| CMT2-5-2 | 22.71 | 17.82 | 1.6895 | 14 | 0.1133 | Same |
| CMT1-5-2 | 22.71 | 29.45 | -2.0147 | 11 | 0.0690 | Same |
| CMT4-5-4 | 22.71 | 23.25 | -0.2160 | 14 | 0.8321 | Same |
| CMT3-5-4 | 22.71 | 29.07 | -2.1751 | 10 | 0.0547 | Same |
| CMT2-5-4 | 22.71 | 17.32 | 1.2802 | 9 | 0.2325 | Same |
| CMT1-5-4 | 22.71 | 19.91 | 0.7724 | 14 | 0.4527 | Same |

Note: df – degree of freedom as per statistical analysis

Table 5.5 and Figure 5.4 rank the temperature variations from lowest to highest. It can be noted that 11 out of the 16 plots have less temperature variations than the Control Plot. This is attributed to the ability of composts to encapsulate thermally and hence preserve moderate temperatures at shallow depths. It acts like an insulator that keeps soil cool in hot weather and keeps soil warm in cold weather. As a result, rapid fluctuations in soil temperature were not recorded in the CMT plots.

Table 5.5: Sorted temperature variations

| **Material** | **Width** | **Thickness** | **Temperature Variation ($^oF$)** |
|---|---|---|---|
| CMT2-10-4 | 10 | 4 | 15.18 |
| CMT4-10-4 | 10 | 4 | 15.57 |
| CMT3-10-4 | 10 | 4 | 15.60 |
| CMT1-10-4 | 10 | 4 | 17.00 |
| CMT2-5-4 | 5 | 4 | 17.32 |
| CMT2-5-2 | 5 | 2 | 17.82 |
| CMT3-10-2 | 10 | 2 | 18.26 |
| CMT4-10-2 | 10 | 2 | 19.56 |
| CMT1-5-4 | 5 | 4 | 19.91 |
| CMT3-5-2 | 5 | 2 | 20.75 |
| CMT2-10-2 | 10 | 2 | 21.43 |
| CP | 10 | 4 | 22.71 |
| CMT4-5-4 | 5 | 4 | 23.25 |
| CMT4-5-2 | 5 | 2 | 24.88 |
| CMT3-5-4 | 5 | 4 | 29.07 |
| CMT1-5-2 | 5 | 2 | 29.45 |
| CMT1-10-2 | 10 | 2 | 30.29 |

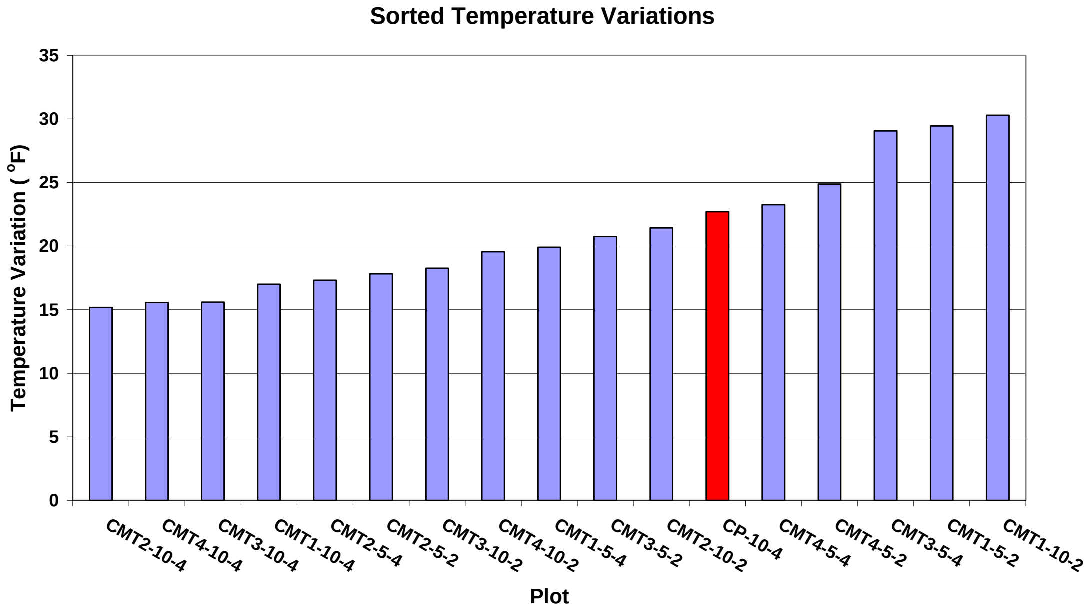



Figure 5.4: Sorted temperature variations

Tables 5.6 and 5.7 as well as Figures 5.5 and 5.6 present the effects of plot thickness and width on temperature variation. By grouping plots by width (5 and 10 feet), the effect of thickness can be clearly seen (Table 5.6 and Figure 5.5). Out of the total of 8 pairs, 7 pairs indicate that plots with thickness of 2 inches have higher temperature variations than plots with 4 inch thickness. This indicates that the compost treatment depth has a direct influence on the temperature fluctuations.

Table 5.6: Effect of treatment depth on temperature variations

| Width (ft) | Material | Thickness (in) | Temperature Variation ($^oF$) |
|---|---|---|---|
| 5 | CMT1 | 2 | 29.45 |
| | CMT2 | 2 | 17.82 |
| | CMT3 | 2 | 20.75 |
| | CMT4 | 2 | 24.88 |
| | CMT1 | 4 | 19.91 |
| | CMT2 | 4 | 17.32 |
| | CMT3 | 4 | 29.07 |
| | CMT4 | 4 | 23.25 |
| 10 | CMT1 | 2 | 30.29 |
| | CMT2 | 2 | 21.43 |
| | CMT3 | 2 | 18.26 |
| | CMT4 | 2 | 19.56 |
| | CMT1 | 4 | 17 |
| | CMT2 | 4 | 15.18 |
| | CMT3 | 4 | 15.6 |
| | CMT4 | 4 | 15.57 |

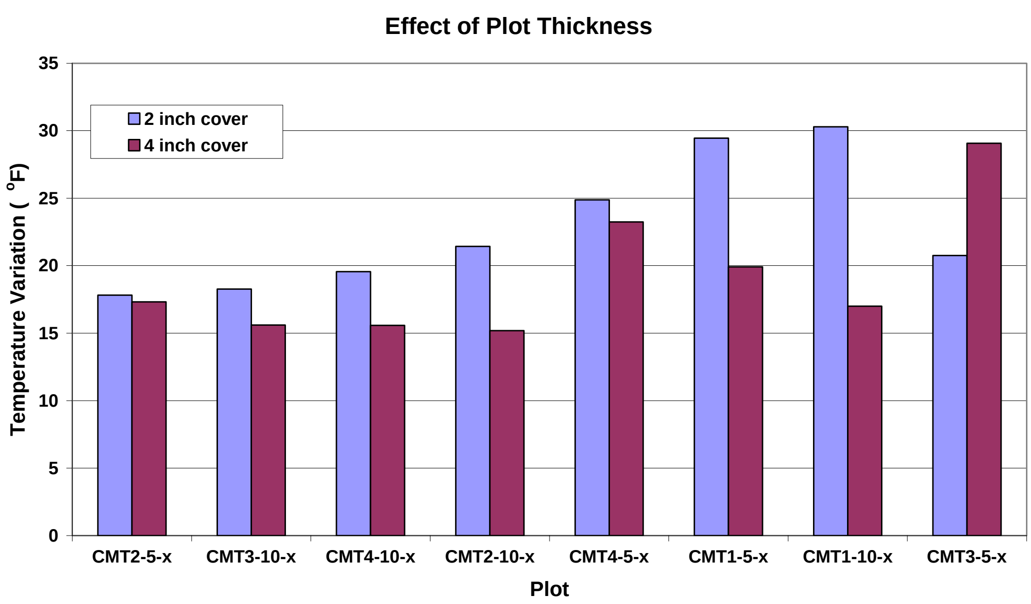



Figure 5.5: Effect of plot thickness

The effect of width in each test plot can also be explained from the following Table 5.7 and Figure 5.6. Six (6) out of the 8 pairs indicate that the plots with width of 5 feet have higher temperature variations than of the 10 foot wide plots. Among all the test plots prepared with composts of 10 foot width, Biosolids Composts provided slightly better thermal encapsulation than Dairy Manure Composts.

Table 5.7: Effect of shoulder width

| **Thickness (in)** | **Material** | **Width (ft)** | **Temperature Variation (°F)** |
|---|---|---|---|
| 2 | CMT1 | 5 | 29.45 |
| | CMT2 | 5 | 17.82 |
| | CMT3 | 5 | 20.75 |
| | CMT4 | 5 | 24.88 |
| | CMT1 | 10 | 30.29 |
| | CMT2 | 10 | 21.43 |
| | CMT3 | 10 | 18.26 |
| | CMT4 | 10 | 19.56 |
| 4 | CMT1 | 5 | 19.91 |
| | CMT2 | 5 | 17.32 |
| | CMT3 | 5 | 29.07 |
| | CMT4 | 5 | 23.25 |
| | CMT1 | 10 | 17 |
| | CMT2 | 10 | 15.18 |
| | CMT3 | 10 | 15.6 |
| | CMT4 | 10 | 15.57 |

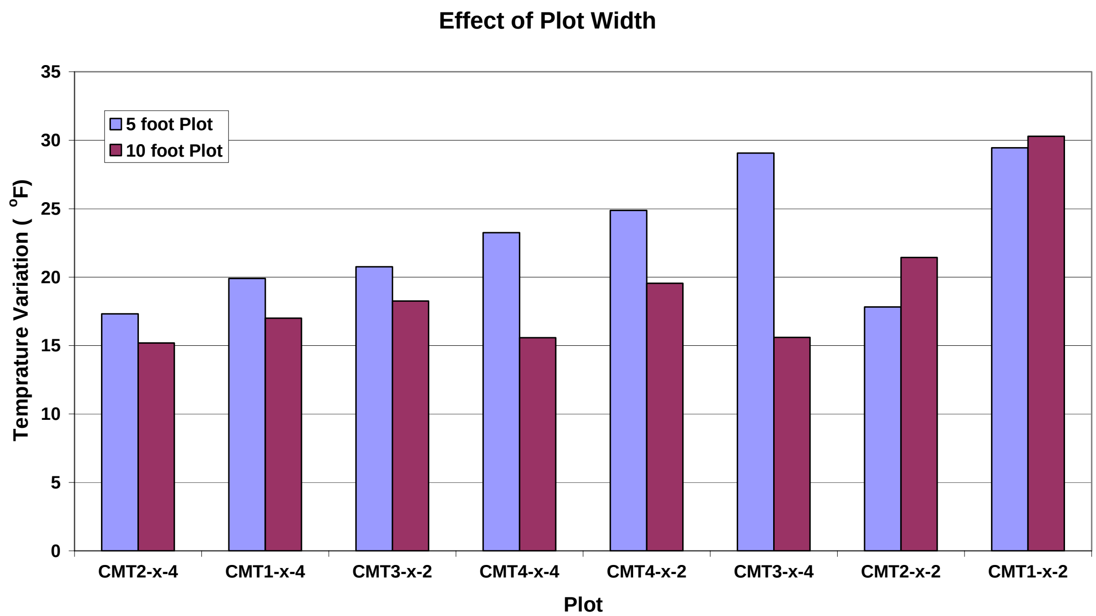



Figure 5.6: Effect of plot width

### 5.3.3 Erosion control

Controlling erosion is a key component in road and highway construction or rehabilitation projects. Roadside embankments, shoulders, medians, and other non-paved surfaces can be vulnerable to eroding forces such as surface runoff and storm events (Middleton et al., 2003). Controlling erosion means stopping soil movement at its source. Compost provides a physical cushion type of barrier between rainfall and the surface soil dissipating the effect of impact energy. Figures 5.7-5.12 show the pictures of subsoil surfaces taken immediately after construction and 3 months after construction, respectively for the three main types of treatment. It can be noted from the figures that soil erosion was a problem in the Control Plot indicating the importance of compost to serve as protective covers. Another item to mention here is that the erosion removes topsoil, which is rich in nutrients. Hence, it reduces the ability of plants to grow in the compacted soils. A reduction in plants or grass growth causes further erosion.

Figure 5.7: Soil surface after construction (CONTROL)

Figure 5.8: Soil surface 3 months after construction (CONTROL)

Figure 5.9: Soil surface after construction (DMC)

Figure 5.10: Soil surface 3 months after construction (DMC)

Figure 5.11: Soil surface after construction (BSC)

Figure 5.12: Soil surface 3 months after construction (BSC)

Plot erosion is an average of erosions at all 5 spikes in each plot. Erosion at each spike can be calculated by subtracting the elevation of each spike by an initial elevation. Plot erosions are then grouped by different CMTs and averaged to determine the final surface erosion. Surface erosions for different CMTs are determined and illustrated in Figure 5.13. About half of the total erosion occurred in the first three months after construction. This could be attributed to the rearrangement of particles, heavy rains during that period and no seeding until 3 months after the construction. Subsequently, the erosions were less than 0.1 ft (1.2 in) over the last 14 months. This lowered erosion is due to the seeding of grass that took place during early Fall in 2003.

Since both Dairy Manure Compost manufactured topsoils (CMT 1 and CMT 2 plots) had less fibrous materials and low vegetation to protect the soil surface from water, they have approximately 50% higher erosion than observed on the Control Plot. As a result of the high amount of fibrous materials which helps in dissipating eroding forces, both Biosolids Compost manufactured topsoils (CMT 3 and CMT 4) have approximately 20% less erosion when compared to the Control Plot.

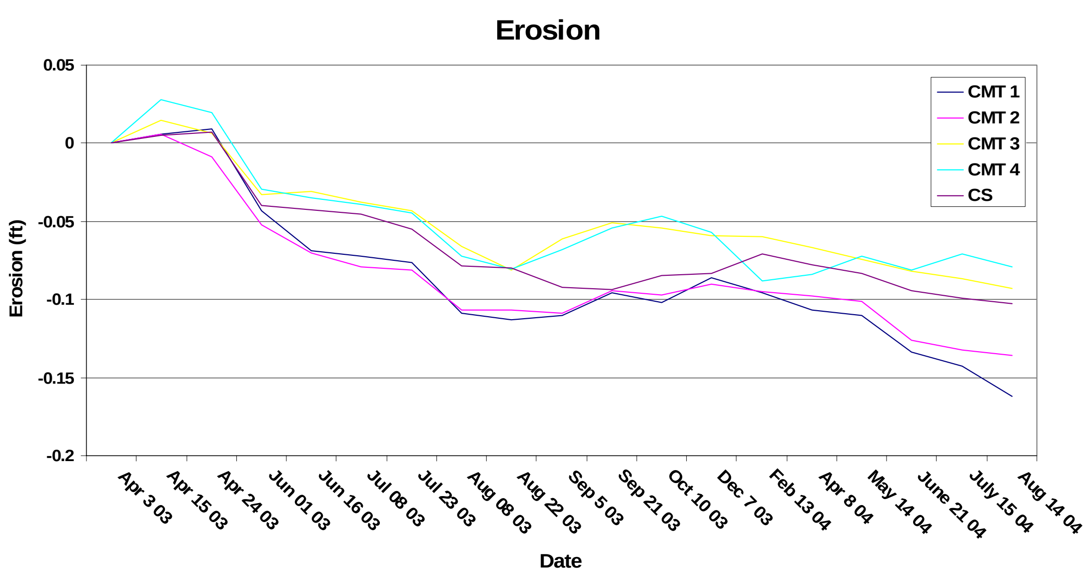



Figure 5.13: Average erosion

### 5.3.4 Digital Image Shrinkage Analysis

Large volumes of expansive subgrades near shrinkage cracks will have moisture access during wet seasons and will start expanding once they are saturated. Hence, it is essential to properly characterize the shrinkage strain potentials of compost surface materials. Due to the size of each test plot, three digital images were randomly taken for each test plot and shrinkage results of these three images were calculated using the procedure described in Chapter 3. These results were used to determine the average shrinkage strain value of each test plot. These digital photos were taken during site visits on days during which no rain was recorded at the site in the past week to represent dry conditions. This data collection and analysis of all the test plots was continued for a total of seventeen months.

Table 5.8 and Figure 5.14 present the digital shrinkage analysis performed on the CMTs. The shrinkage strain values reported are the average values over the entire monitoring period. It can be concluded that Biosolids Compost plots (CMT 3 and 4 plots) have less cracking than the Control Plot. This is attributed to the fibrous materials (woodchips) present in the BSC. These materials act like reinforcements which can withstand tensile forces generated from drying of the soil. Goldsmith (2001) also reported that root systems can increase the tensile strength of soil. On the other hand, DMC which had less fibrous materials (wood trimmings) to sustain tensile forces, experienced higher shrinkage cracking.

Table 5.8: Shrinkage cracking analysis

| Plot name | Compost Type | CP Mean Shrinkage | Plot Mean Shrinkage | t-value | df | 1-sided p-value | 2-sided p-value | Cracking |
|---|---|---|---|---|---|---|---|---|
| CMT4-10-4 | BSC | 0.1351 | 0.0866 | 3.6290 | 21 | 0.0008 | 0.0016 | Less |
| CMT3-10-4 | BSC | 0.1351 | 0.0800 | 3.2974 | 21 | 0.0017 | 0.0034 | Less |
| CMT2-10-4 | DMC | 0.1351 | 1.1946 | -7.8313 | 21 | 0.0000 | 0.0000 | More |
| CMT1-10-4 | DMC | 0.1351 | 1.2516 | -6.5306 | 20 | 0.0000 | 0.0000 | More |
| CMT4-10-2 | BSC | 0.1351 | 0.0814 | 3.3444 | 21 | 0.0015 | 0.0031 | Less |
| CMT3-10-2 | BSC | 0.1351 | 0.0730 | 4.8645 | 21 | 0.0000 | 0.0001 | Less |
| CMT2-10-2 | DMC | 0.1351 | 0.7772 | -3.9127 | 21 | 0.0004 | 0.0008 | More |
| CMT1-10-2 | DMC | 0.1351 | 0.6408 | -3.1802 | 21 | 0.0023 | 0.0045 | More |
| CMT4-5-2 | BSC | 0.1351 | 0.1110 | 0.5427 | 21 | 0.2965 | 0.5930 | Same |
| CMT3-5-2 | BSC | 0.1351 | 0.0723 | 4.3967 | 21 | 0.0001 | 0.0003 | Less |
| CMT2-5-2 | DMC | 0.1351 | 0.7762 | -4.1712 | 21 | 0.0002 | 0.0004 | More |
| CMT1-5-2 | DMC | 0.1351 | 0.1955 | -1.0351 | 21 | 0.1562 | 0.3124 | Same |
| CMT4-5-4 | BSC | 0.1351 | 0.0576 | 4.5434 | 21 | 0.0001 | 0.0002 | Less |
| CMT3-5-4 | BSC | 0.1351 | 0.0881 | 2.4485 | 21 | 0.0116 | 0.0232 | Less |
| CMT2-5-4 | DMC | 0.1351 | 0.7150 | -3.8342 | 27 | 0.0003 | 0.0007 | More |
| CMT1-5-4 | DMC | 0.1351 | 0.6238 | -2.6071 | 23 | 0.0079 | 0.0158 | More |

Note: df – degree of freedom

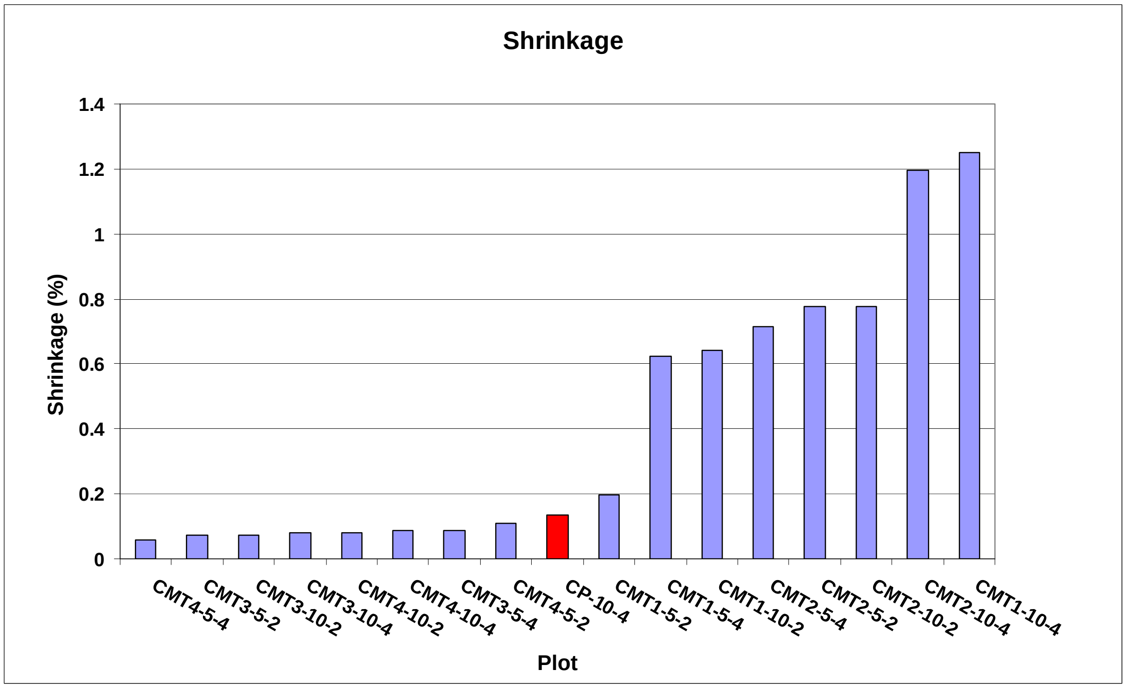



Figure 5.14: Shrinkage cracking in the test plots

Compost plot widths and thicknesses did not show any major influence on the shrinkage cracking as the cracking appears to be dependent of the material type used for the topsoil amendments.

Table 5.9 and Figure 5.15 also show the maximum shrinkage strain recorded in each plot during the monitoring period. All BSC plots with the exception of CMT4-5-2 experienced less shrinkage cracking than that of the Control Plot. This also concurs with the other CMT performances mentioned earlier by the Biosolids Composts. From this, it can be concluded that the BSC has the ability to restrain and mitigate desiccation shrinkage cracking better than the DMC.

Table 5.9: Maximum shrinkage strains in test plots

| **Plot** | **Compost** | **Shrinkage** |
|---|---|---|
| CMT3-10-2 | BSC | 0.17 |
| CMT4-10-4 | BSC | 0.17 |
| CMT3-5-2 | BSC | 0.18 |
| CMT4-5-4 | BSC | 0.20 |
| CMT3-10-4 | BSC | 0.23 |
| CMT4-10-2 | BSC | 0.23 |
| CMT3-5-4 | BSC | 0.31 |
| CP-10-4 | - | 0.34 |
| CMT1-5-2 | DMC | 0.64 |
| CMT4-5-2 | BSC | 1.04 |
| CMT1-5-4 | DMC | 1.47 |
| CMT2-10-2 | DMC | 1.71 |
| CMT1-10-2 | DMC | 1.81 |
| CMT2-5-4 | DMC | 1.93 |
| CMT2-5-2 | DMC | 1.93 |
| CMT2-10-4 | DMC | 2.03 |
| CMT1-10-4 | DMC | 2.53 |

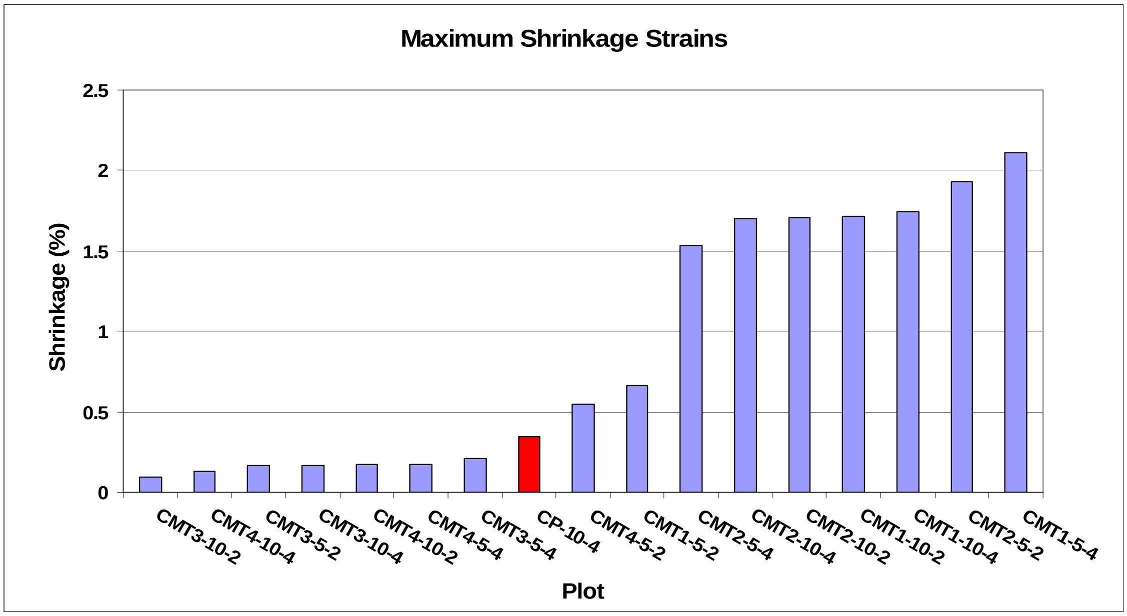



Figure 5.15: Maximum shrinkage strains

### 5.3.5 Pavement Shoulder Cracking

Pavement shoulder cracking can be attributed to moisture intrusion into the adjacent shoulder subgrade layers due to either desiccation cracking or shrinkage cracking movements. Less cracking on paved shoulders could be used to identify the CMT's effectiveness as an acceptable cover material. Figure 5.16 and 5.17 show a few digital images of pavement shoulder cracks adjacent to the Control Plot taken at different time periods during monitoring. In the first picture, a few longitudinal cracks can be seen. The next image, which was taken a year later, shows the widening and joining of the cracks. Due to the high amount of shrinkage cracking in the Control Plot, paved shoulders exhibited unacceptable cracking. This allowed water intrusion into the underlying subsoils, which further weakened the subgrade. As a result, the paved surface experienced further cracking and widening of existing cracks as shown in Figure 5.17.


Figure 5.16: Paved shoulder on Apr 2003


Figure 5.17: Paved shoulder on Apr 2004

Pavement crack images taken at all the other sixteen plots are presented in Appendix B. Table 5.10 presents the results of visual observations of these images on all the test plots. Cracks could be found on the plots which were treated with both composts at 5 ft width and 2 in. thickness. Since Plots 9 to 12 have the smallest amounts of composts to retain moisture (5 feet x 2 in.), excess water was still able to infiltrate into the subgrade. Cracks in Plots 8 and 13 are most likely the propagation of cracks from Plots 9 and 12 respectively.

Table 5.10: Paved shoulder cracking

| Plot name | Plot No. | Compost | Visual Observation |
|---|---|---|---|
| CMT4-10-4 | 1 | BSC | No new cracks |
| CMT3-10-4 | 2 | BSC | No new cracks |
| CMT2-10-4 | 3 | DMC | No new cracks |
| CMT1-10-4 | 4 | DMC | No new cracks |
| CMT4-10-2 | 5 | BSC | No new cracks |
| CMT3-10-2 | 6 | BSC | No new cracks |
| CMT2-10-2 | 7 | DMC | No new cracks |
| CMT1-10-2 | 8 | DMC | New Cracks |
| CMT4-5-2 | 9 | BSC | New Cracks |
| CMT3-5-2 | 10 | BSC | New Cracks |
| CMT2-5-2 | 11 | DMC | New Cracks |
| CMT1-5-2 | 12 | DMC | New Cracks |
| CMT4-5-4 | 13 | BSC | New Cracks |
| CMT3-5-4 | 14 | BSC | No new cracks |
| CMT2-5-4 | 15 | DMC | No new cracks |
| CMT1-5-4 | 16 | DMC | No new cracks |
| CP-10-4 | 17 | - | New Cracks |

### 5.3.6 Vegetation Reestablishment

In pavement construction practice, soil compaction and topsoil removal often result in unprotected, unnourished and impenetrable ground surfaces. This can have severe effects on vegetation reestablishment, which in turn leads to higher erosion, increased runoff, and other consequences of pavement distress. Figures 5.18 through 5.20 show the visual appearances of vegetation after the initial construction of all the plots. It should be mentioned that only a small amount of vegetation can be seen on the Control Plot as it was prepared without any topsoil removal and compaction. However, on all the compost plots, no vegetation was observed since topsoil surfaces were disturbed as a result of removal, tilling and compaction.

Figure 5.18: Visual appearance of vegetation of Control Plot

Figure 5.19: Visual appearance of vegetation of Dairy Manure Compost plot

Figure 5.20: Visual appearance of vegetation of Biosolids Compost plot

Table 5.11 summarizes the reestablishment of vegetation of all the test plots by seeding them in early September 2003. The vegetation data was collected via digital images taken on October 10, 2003, which was approximately 6 months after the construction. Figures 5.21 through 5.23 show typical pictures of the CS, DMC and BSC plots, respectively. It can be seen that the Control Plot had slight vegetation growth and most DMC plots (CMT 1 and CMT 2) plots have none to slight vegetation growth on them. On the other hand, the BSC plots (CMT 3 and CMT 4) have average to high vegetation growth. The lack of vegetation in the DMC plots could be the result from the higher compaction density of surficial soil during the construction of those test plots. Due to low organic content, the DMC CMTs behaved similar to natural and untreated soils. Goldsmith et al. (2001) reported that when soil compaction levels are high, there appears to be a threshold soil bulk density value beyond which roots are unable to penetrate due to high mechanical resistant of soils.

Table 5.11: Vegetation reestablishment on October 10, 2003

| Plot name | Plot No. | Visual Observation |
|---|---|---|
| CMT4-10-4 | 1 | Thick |
| CMT3-10-4 | 2 | Thick |
| CMT2-10-4 | 3 | Low |
| CMT1-10-4 | 4 | Low |
| CMT4-10-2 | 5 | Average |
| CMT3-10-2 | 6 | Average |
| CMT2-10-2 | 7 | None |
| CMT1-10-2 | 8 | Low |
| CMT4-5-2 | 9 | Thick |
| CMT3-5-2 | 10 | Average |
| CMT2-5-2 | 11 | None |
| CMT1-5-2 | 12 | None |
| CMT4-5-4 | 13 | Thick |
| CMT3-5-4 | 14 | Thick |
| CMT2-5-4 | 15 | Thick |
| CMT1-5-4 | 16 | Thick |
| CP-10-4 | 17 | Slight |

Figure 5.21: Visual appearance of Control Plot

Figure 5.22: Visual appearance of Dairy Manure Compost plot

Figure 5.23: Visual appearance of Biosolids Compost plot

From the nuclear gauge density results conducted after the compaction of the test plots (Figure 5.24), it can be seen that the actual compaction dry density values of the test plots after construction came close to the recommended dry density values for construction. As a result, both CMT 1 and CMT 2 plots have high compaction densities (more than 90 pcf) where as CMT 3 and CMT 4 plots have low compaction densities (less than 80 pcf). It should be noted here that the Control Plot was not recompacted and the original vegetation was allowed to grow on the same plot. Although compaction was not performed on the Control Plot, the actual density of this plot was high (as per the moisture-density measurements), which might have resulted in low amount of vegetation.

Tyler (2003) reported that in general, a compaction between 80-85 percent of the standard proctor maximum dry unit weight or density optimizes the performance of slope stability with vegetation development and growth. In the present case, this criterion did affect the vegetation growth in certain plots whose relative compactions were above 90%. Vegetation was noted on the compost test plots whose compaction densities were less than 80 pcf (relative compactions less than 85%) and not noted extensively on test plots whose compaction densities were more than 90 pcf (relative compactions more than 85%). However, with continuous seeding, one expects the vegetation growth even on the Dairy Manure Compost test plots.

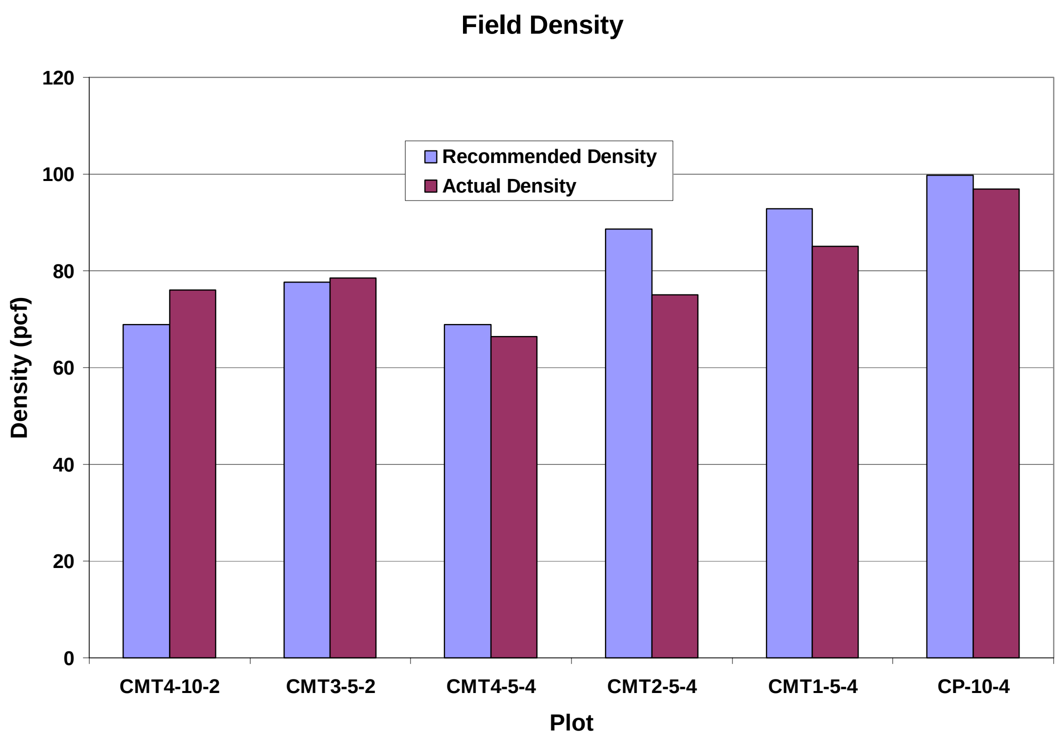



Figure 5.24: Actual and recommended field dry densities

Another reason for the lack of vegetation on the DMC (CMT 1 and CMT 2) and Control Plot is the amount of low organic content in both the amended and top soil. ASTM standard test method for Organic Content determination (D-2974) was performed on pure and amended soils to measure the percentage of organic matter. The organic content results are presented in Table 5.12.

The maximum percentage of organics was present in BSC_30 and the minimum percentage was present in the CS. The reason for the high organic percentage in BSC_30 was due to the presence of wood chips, rice husk and other organic material used in the composting process of the biosolids. In the case of dairy manure materials, the organic material present is low due to limited mixing of organic fibrous material used in the composting process of dairy manure (Pokala, 2003).

Table 5.12: Organic content percentages of pure and amended soils

| Soil Description | Organic Content (%) |
|---|---|
| CS (Control Soil) | 5.92 |
| DMC_75 (25% Control Soil, 75% DMC) | 8.86 |
| DMC_100 (100% DMC) | 9.94 |
| BSC_20 (80% Control Soil, 20% BSC) | 11.76 |
| BSC_30 (70% Control Soil, 30% BSC) | 14.52 |

The normal practice during the construction process is to establish vegetation by seeding immediately after construction. Hence, when compost amended soils are used as cover material, seeding needs to be performed on top of the compost layers. Using both seeding and compost applications will enhance vegetation growth on test plots (Tyler et al., 2003).

## 5.4 Recommendations Based on Ranking Analysis

This section evaluates the overall performance of all the CMTs. The evaluation is based on shrinkage cracking, moisture content and temperature fluctuations, erosion, paved shoulder cracking and vegetation growth of all the plots. The evaluation and recommendations are shown in Table 5.13. Since paved shoulder cracking indicates the ability of CMTs to protect the integrity of roadways, more importance was given to this observation. Hence, any plots with paved shoulder cracking are not recommended for future composting applications.

It can be noted that plots treated with Biosolids Composts for 10 feet wide and 4 in. depth, both unpaved and paved shoulders performed satisfactorily with no cracking distress. Hence, both CMT3 and CMT4 are recommended from the research. Although the DMC plots are not recommended, a few of the DMC plots did not show any paved shoulder cracking. Therefore, one should not rule out the possibility of using DMCs at different dosages. Future research should explore the possibility of using DMCs at low proportions for soil amendments and then assess their performance on mitigating desiccation cracks.

## 5.5 Summary

This chapter describes various details on data collected from moisture and temperature sensors, erosion surveys, digital image cracking studies, and visual observations of paved shoulder cracking and vegetation growth of all sixteen test plots and one Control Plot. This data was analyzed with statistical comparison tests to evaluate the effectiveness of compost amendments to reduce desiccation cracking in subsoils. The final outcome of this analysis is the recommendation of Biosolids Compost amendments to control moisture and temperature fluctuation in subsoils from surrounding environments and reduce shrinkage cracking and erosion losses. All these enhancements resulted in lesser paved shoulder cracking. Dairy Manure Composts, on the other hand, resulted in erosion loss and shrinkage cracking of soils and hence resulted in adjacent paved shoulder cracking, which is similar to the problems recorded on the Control Plot with no compost amendments. Hence, these materials are currently recommended in their original form. However, addition of fibrous materials during composting process is expected to enhance the performance of these materials.

Table 5.13: Evaluation and recommendation of CMTs

| Plot Name | Enhancement? | | | | | | Final Recommendation |
|---|---|---|---|---|---|---|---|
| | Shrinkage | Temp Variation | Moisture Variation | Erosion | Paved Shoulder Cracking | Vegetation | |
| CMT1-5-2 | - | x | ✓ | x | X | x | x |
| CMT2-5-2 | X | ✓ | ✓ | x | X | x | x |
| CMT3-5-2 | ✓ | ✓ | ✓ | ✓ | X | ✓ | x |
| CMT4-5-2 | - | x | x | ✓ | X | ✓ | x |
| CMT1-5-4 | X | ✓ | - | x | ✓ | ✓ | x |
| CMT2-5-4 | X | ✓ | ✓ | x | ✓ | ✓ | x |
| CMT3-5-4 | ✓ | x | x | ✓ | ✓ | ✓ | ✓ |
| CMT4-5-4 | ✓ | x | x | ✓ | X | ✓ | x |
| CMT1-10-2 | X | x | x | x | X | - | x |
| CMT2-10-2 | X | ✓ | x | x | ✓ | x | x |
| CMT3-10-2 | ✓ | ✓ | x | ✓ | ✓ | ✓ | ✓ |
| CMT4-10-2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| CMT1-10-4 | X | ✓ | x | x | ✓ | - | x |
| CMT2-10-4 | X | ✓ | ✓ | x | ✓ | - | x |
| CMT3-10-4 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| CMT4-10-4 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Note: ✓ **- Effective; x – Not Effective; - - No change.**

# CHAPTER 6
# SUMMARY OF FINDINGS AND FUTURE RESEARCH

## 6.1 Introduction

The research covered in this report consists of both laboratory and field investigations designed to evaluate the performance of Compost Manufactured Topsoils to mitigate desiccation cracking of expansive shoulder subgrades. The following conclusions are developed from the analyses presented in Chapters 4 and 5. These conclusions are based on the majority of the trends noted in the present data. These conclusions may not be extended beyond those composts tested in this research study without proper verifications.

## 6.2 Summary of findings

The following lists both major and a few specific conclusions obtained from the field study phase of this research.

### *6.2.1 Major Conclusions*

Based on the comprehensive field data collection and analysis, it can be concluded that the Biosolids Compost amendments provided the best expansive soil property enhancements resulting in lesser shrinkage cracking of expansive shoulder subsoils than those observed from the control soil. This effectiveness is verified by several types of data collected from the field studies including moisture and temperature variations as well as digital image analyses of subsoil shrinkage cracking and visual observations of paved shoulder cracking. These results indicate that the BSC amendments lead to mitigating of shrinkage cracking in subsoils and thereby reduced paved shoulder cracking. Best performance of these material amendments were recorded when these CMTs were constructed 10 ft wide and 4 in. thick.

Though DMC provided moderate enhancements, it should be noted here that this material performance was negatively impacted due to low amounts of fibrous or organic material in them. Hence, DMC treatment with fibrous material is expected to enhance its' performance in mitigating shrinkage cracking.

A few other specific conclusions were established based on the present data analysis, which are presented in the following.

### *6.2.2 Specific Conclusions*

1. Compaction moisture content variations of CMT plots and the Control Plots measured from moisture sensors located at 6 in. depth were similar. However, when average moisture content variations were ranked by their magnitudes, nine out of the sixteen CMT plots had lesser moisture variations than that of the Control Plot.
2. Moisture content data records also showed the ability of CMT to preserve moisture in subgrades. Moisture contents in most of the CMT plots never went below the initial compaction moisture contents indicating that the composts preserved the moistures in the underlying subsoils.
3. The majority of temperature variations at 6 in. depth in the test plots were not statistically different when compared to that of the Control Plot. However, eleven out of the sixteen compost test plots showed that they had lesser temperature variations than that of the Control Plot. This indicates the ability of composts to insulate soils from surficial temperatures.

4. Compost plot width and thickness indicated an influence on soil temperature conditions. Plots with the same width but with 2 in. treatment depth tended to have higher temperature fluctuations than the same plots with 4 in. treatment depth. Plots of the same thickness with 5 foot width showed higher temperature fluctuations than plots with 10 foot width treatment.
5. Due to the fibrous materials, Biosolids Compost served as an erosion control blanket. Overall, Biosolids Compost plots had approximately 20% less erosion than the Control Plot. On the other hand, Dairy Manure Compost plots, due to low fibrous materials, experienced more erosion (more than 50%) than the Control Plot.
6. The majority of the total erosion occurred within the first few months. This is attributed to lack of vegetation, heavy rain and rearrangement of CMT particles. It is recommended that seeding be done immediately after construction to prevent the early erosion loss of compost materials.
7. Biosolids Compost plots experienced less desiccation cracking when compared to the Control Plot. This is attributed to fibrous materials (from the composting process of woodchips) present in the BSC. These materials serve as natural reinforcements in the materials; hence they can withstand or resist tensile forces generated from the drying of the subsoil. The lack of fibrous materials in the DMC may have resulted in higher desiccation cracking.
8. Paved shoulder cracking mostly occurred in the CMT test plots with 5 ft width and 2 in. treatment depth and in the Control Plot. Cracking was attributed to both desiccation and erosion problems observed in these plots.
9. Lack of sufficient organic contents and high compaction density were the main causes of low vegetation on the DMC plots. Compaction densities, as reported in

RR-1, in Dairy Manure Compost, Biosolids Compost and the Control Soil were approximately 99.7, 90.8 and 73.3 pcf, respectively. Organic contents in the same materials were 5.9, 9.4 and 13.1%, respectively. As a result, vegetation density was higher in the Biosolids Compost plots than in the Dairy Manure Compost plots.

10. The student *t*-test analysis clearly indicated that the surface runoff samples collected from Compost Manufactured Topsoils contain higher concentrations of contaminants than that from the Control Plot. Furthermore, the surface runoff from the DMC manufactured topsoil has higher concentrations than the runoff sample from the BSC manufactured topsoil.

11. Comparisons of surface runoff quality from Compost Manufactured Topsoil with US EPA benchmark and NCTCOG measured values indicates that certain pollutant concentrations in surface runoff from Compost Manufactured Topsoils were higher than the benchmark and NCTCOG measured values. These values were probably higher because of the high proportion of composts used in the manufactured topsoil, and due to sample collection points located immediately at the end of the test plots. If the proportion of compost is lowered, and the sampling point is located in the surface drain, pollutant concentration in runoff will be lowered due to dilution effects.

## 6.3 Research Recommendations

Biosolids Compost plots are recommended for compost amendments to control desiccation cracks. Both proportions (20 and 30% of BSC by dry weight) provided better encapsulation and lesser cracking in subsoils and adjacent pavements. Shoulder widths of 10 ft and treatment depth of 4 in. are recommended in these compost treatments in the field.

## 6.4 Future Research

The following lists a few important future research needs:

1. Further monitoring is recommended on these test plots to address the long-term stability of compost amendments on the present test plots.
2. Cost benefit studies using long term field monitoring data should be conducted to understand the cost effectiveness of compost treated soils.
3. Potential applications for composts in different soil types and regions, with different climatic conditions should be evaluated.
4. Leachate (refers to water that emanates from these materials) collected from the field should be assessed environmentally.
5. Life pertaining to potential decomposition of the compost materials in the CMT plots should be addressed.
6. The surface runoff quality emanating from compost applied sites should be assessed over a long time.

Client Note:

Items 1 and 3 have been included for Implementation Project 5-4573. This report will be available in November 2005.

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# Appendix A: Moisture and Temperature Data

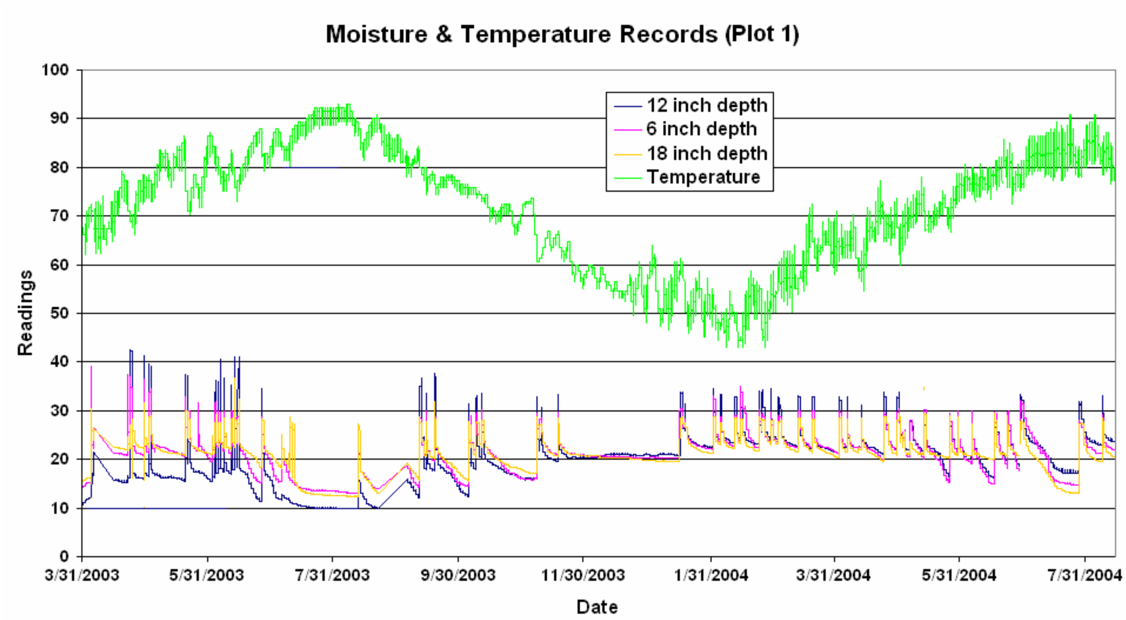


Figure A1: Plot 1 (CMT4-10-4)

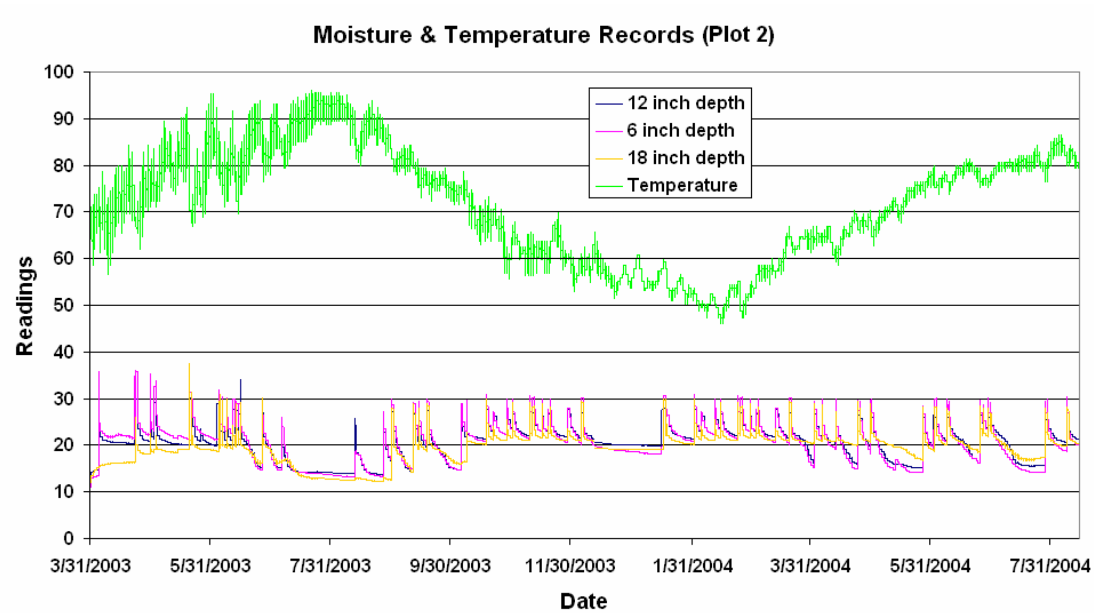


Figure A2: Plot 2 (CMT3-10-4)

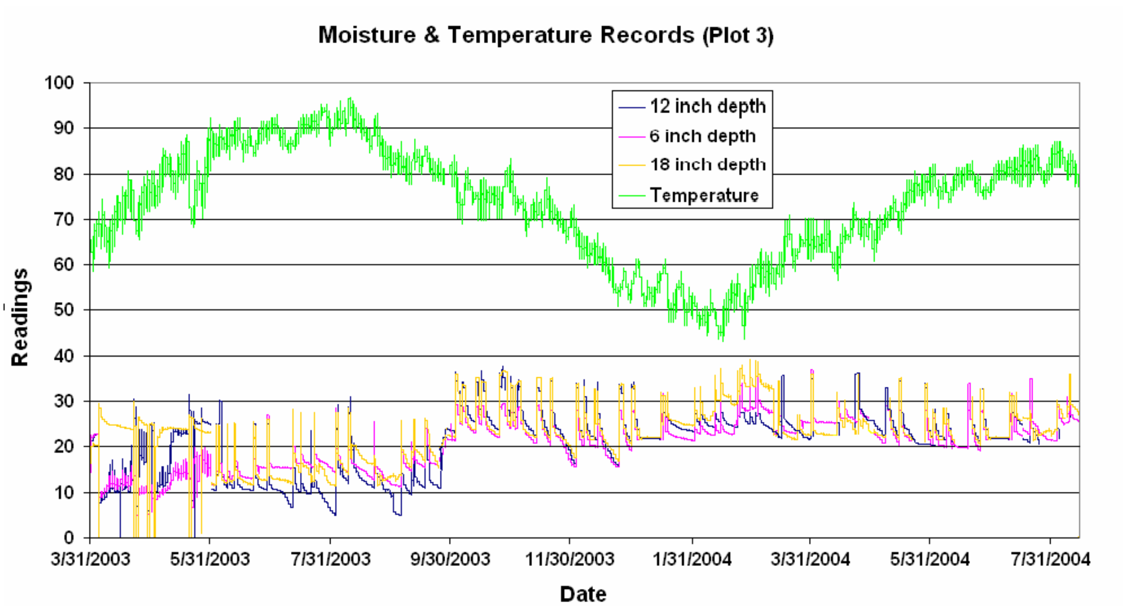


Figure A3: Plot 3 (CMT2-10-4)

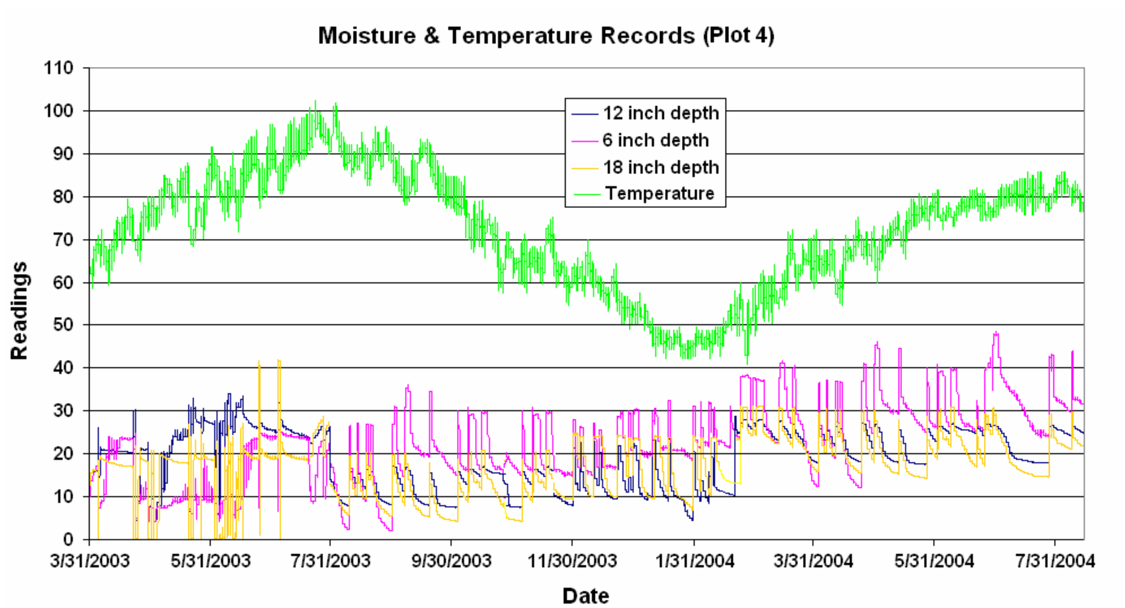


Figure A4: Plot 4 (CMT1-10-4)

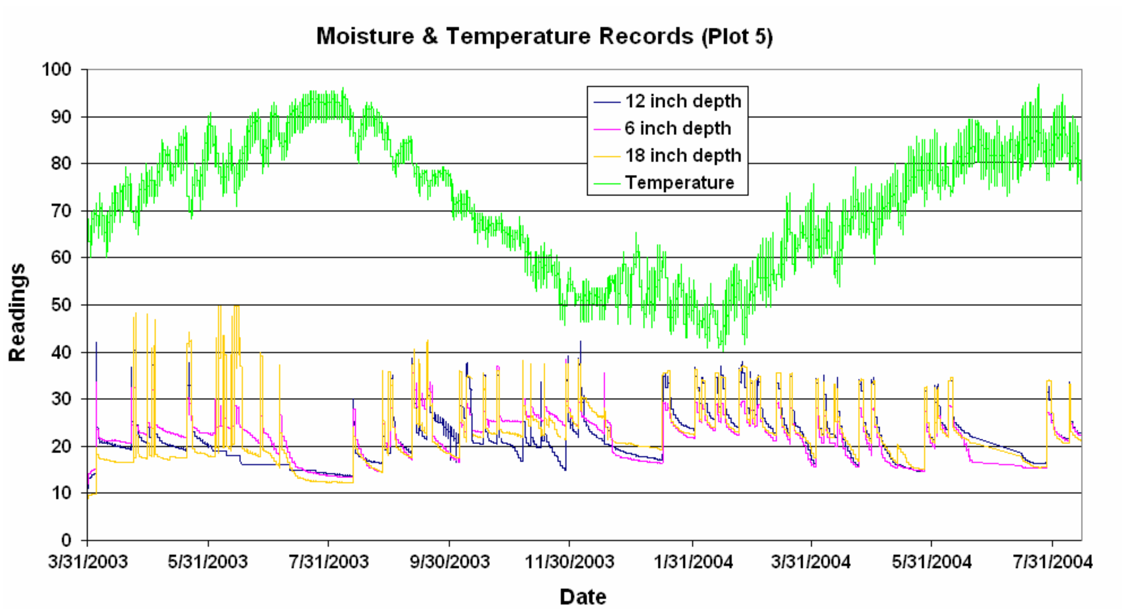


Figure A5: Plot 5 (CMT4-10-2)

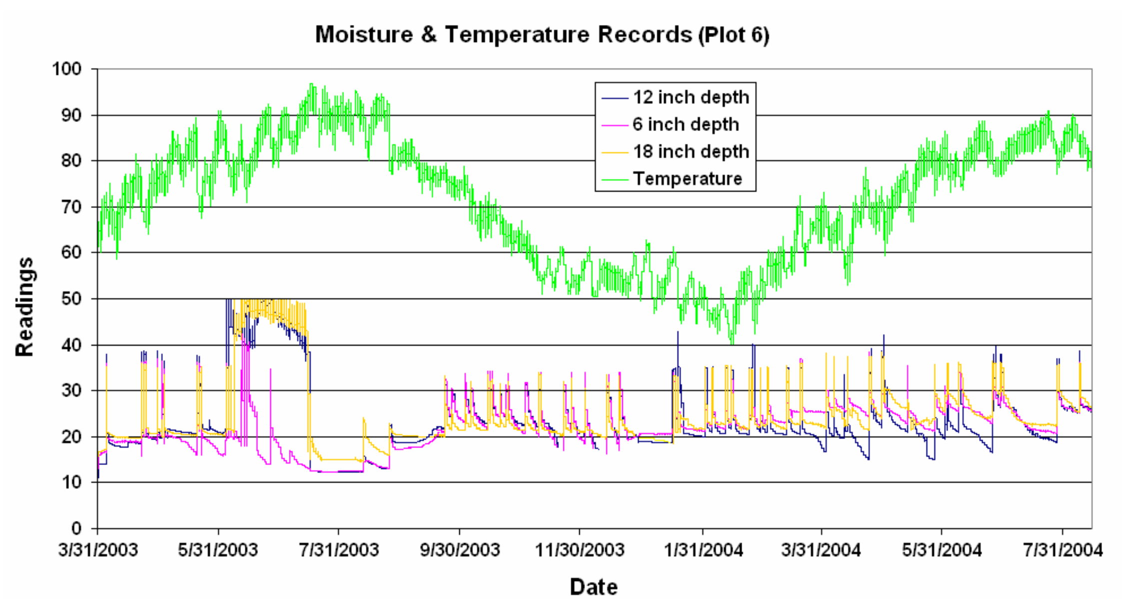


Figure A6: Plot 6 (CMT3-10-2)

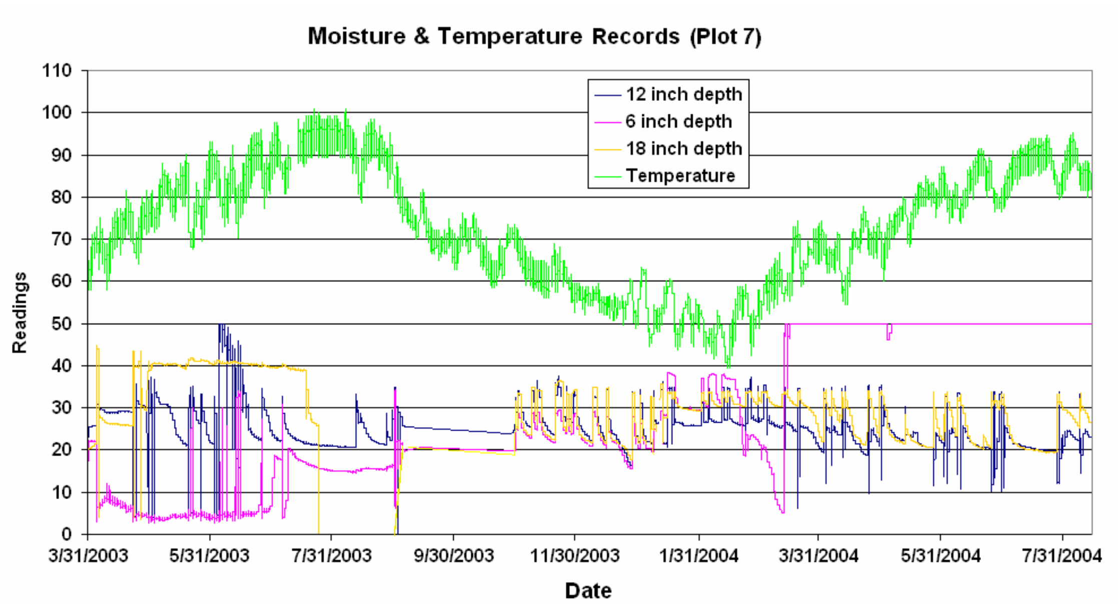


Figure A7: Plot 7 (CMT2-10-2)

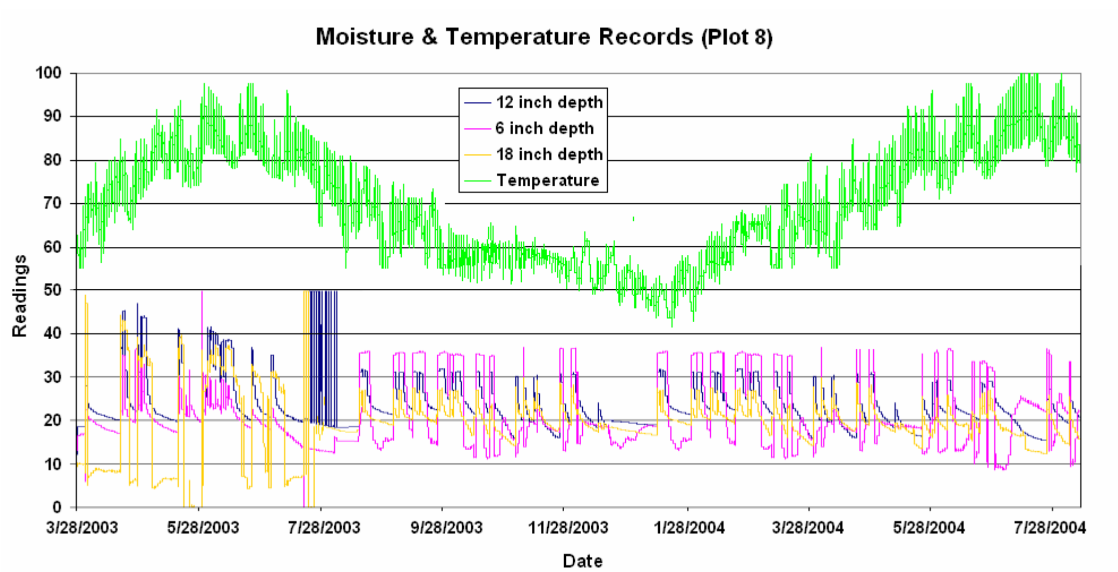


Figure A8: Plot 8 (CMT1-10-2)

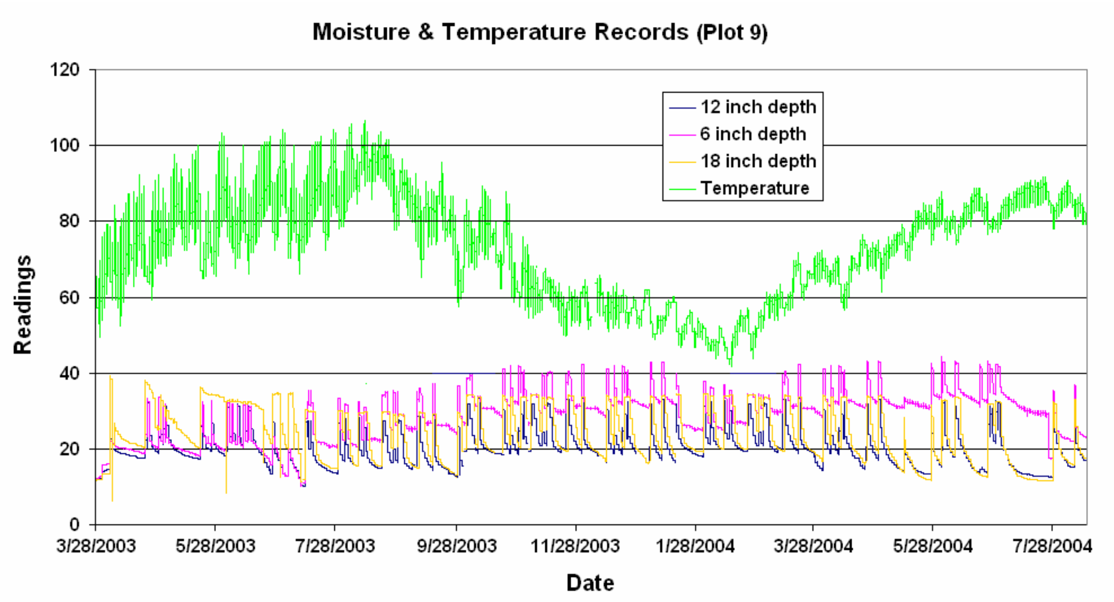


Figure A9: Plot 9 (CMT4-5-2)

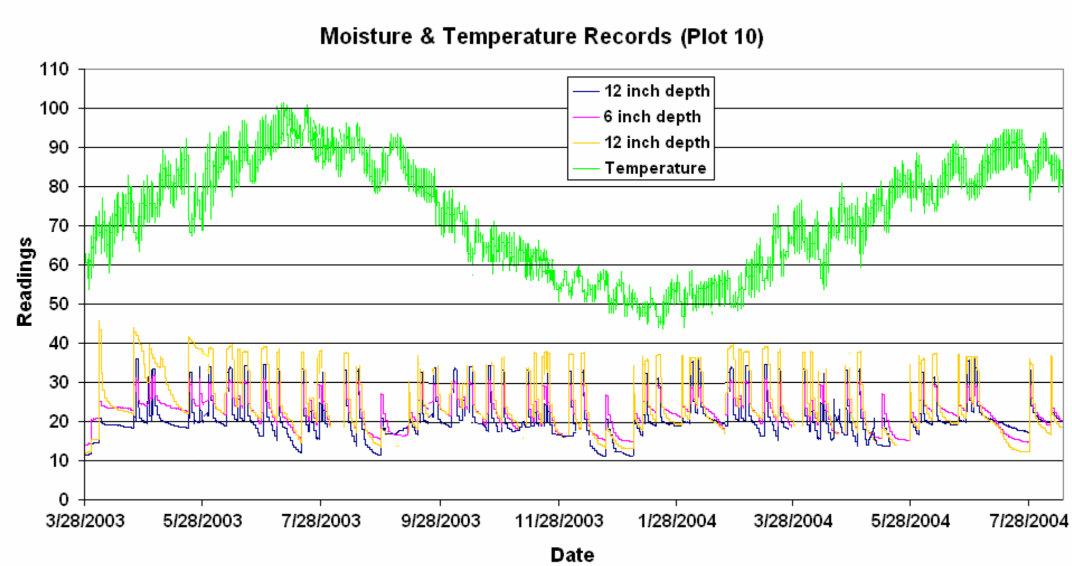


Figure A10: Plot 10 (CMT3-5-2)

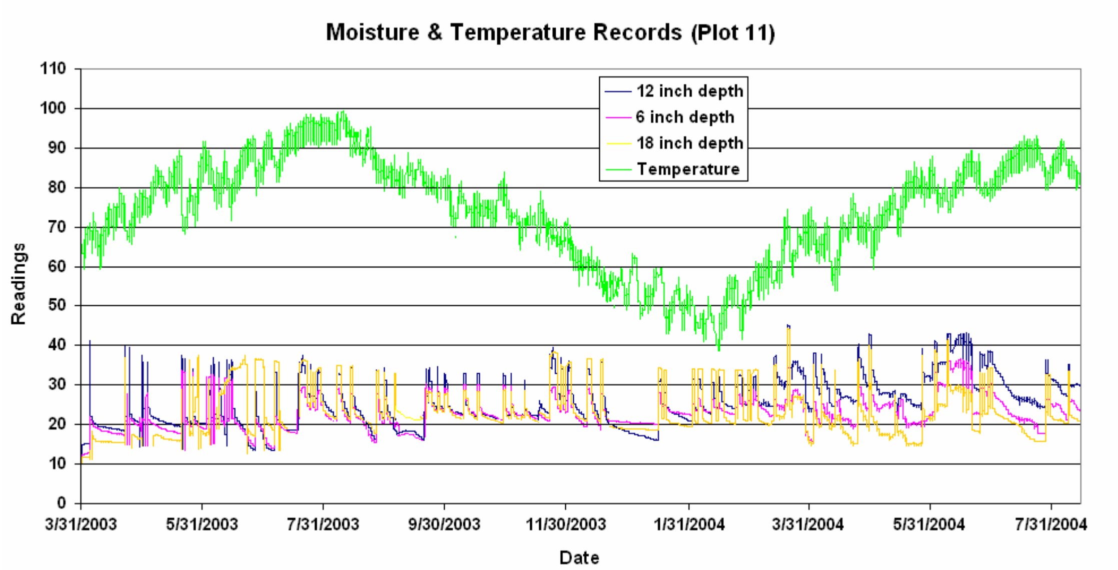


Figure A11: Plot 11 (CMT2-5-2)

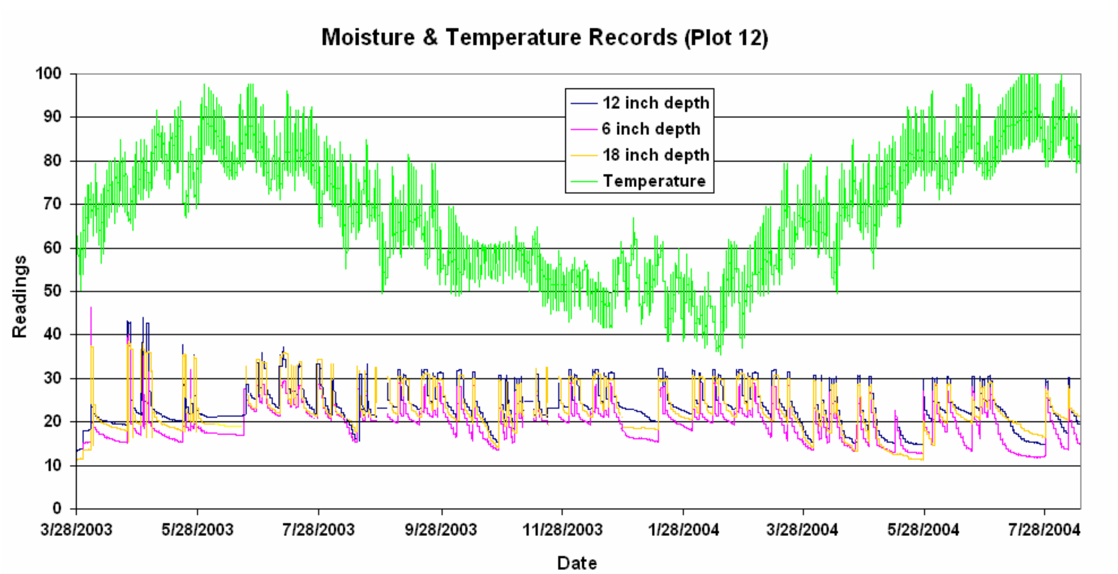


Figure A12: Plot 12 (CMT1-5-2)

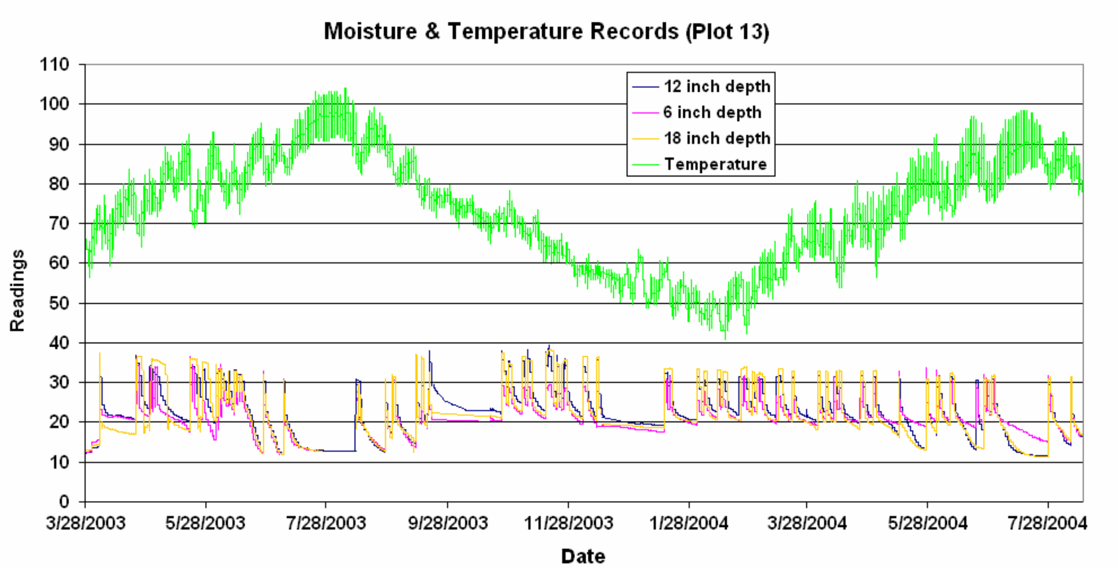


Figure A13: Plot 13 (CMT4-5-4)

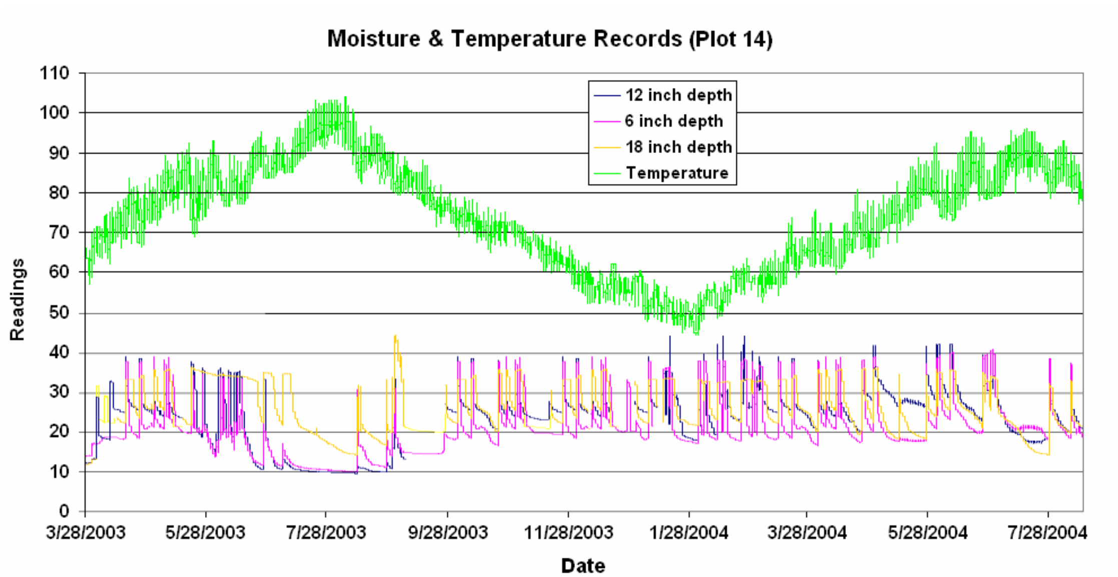


Figure A14: Plot 14 (CMT3-5-4)

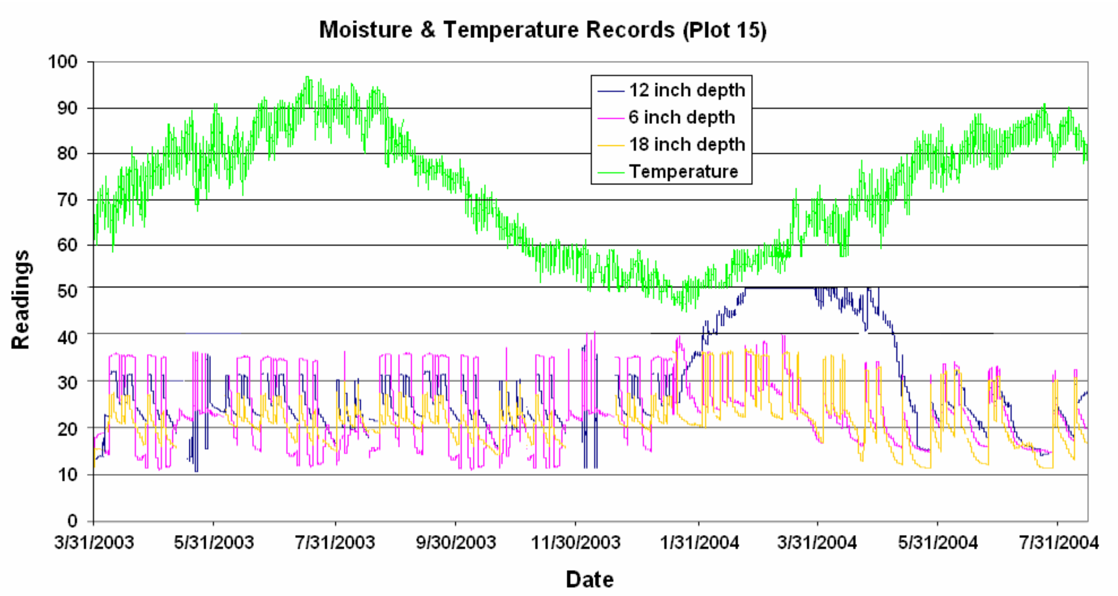


Figure A15: Plot 15 (CMT2-5-4)

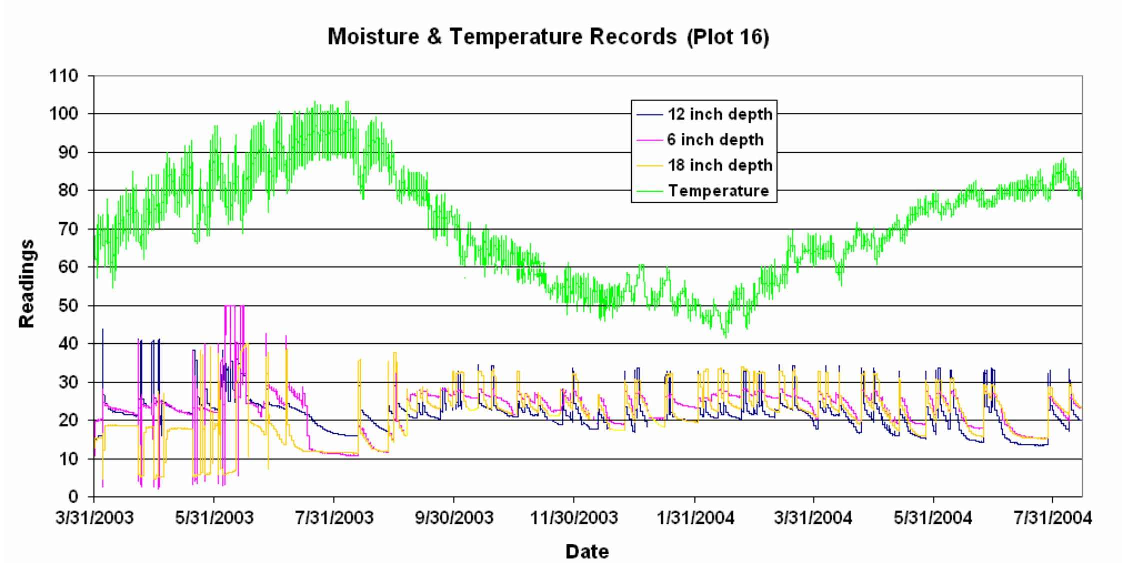


Figure A16: Plot 16 (CMT1-5-4)

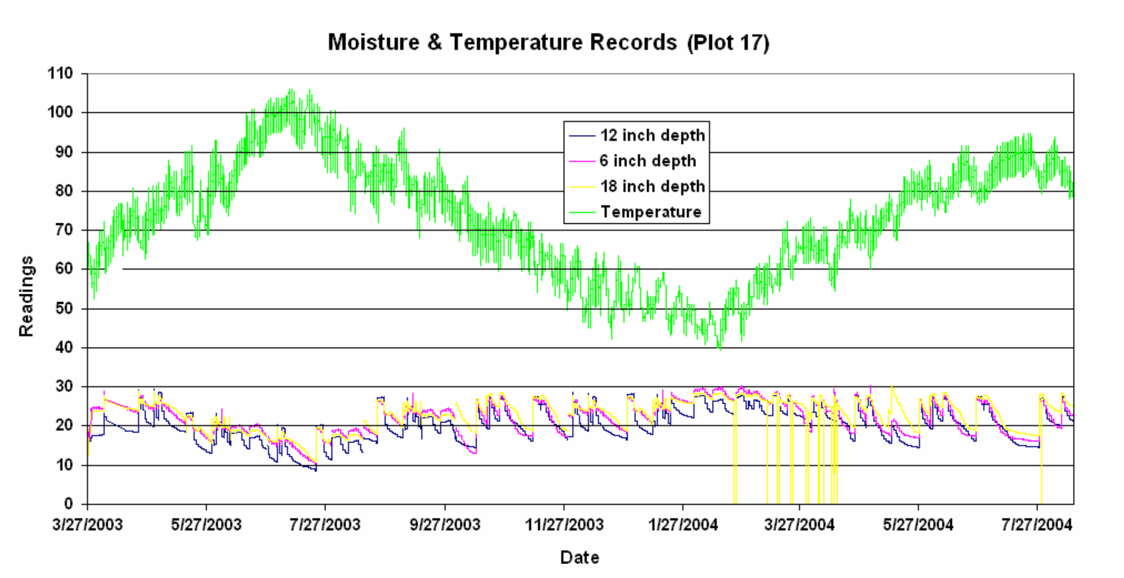


Figure A17: Plot 17 (CP-10-4)

# Appendix B: Paved Shoulder Cracking

Figure B1: Plot 1 (CMT4-10-4)

Figure B2: Plot 2 (CMT3-10-4)

Figure B3: Plot 3 (CMT2-10-4)

Figure B4: Plot 4 (CMT1-10-4)

Figure B5: Plot 5 (CMT4-10-2)

Figure B6: Plot 6 (CMT3-10-2)

Figure B7: Plot 7 (CMT2-10-2)

Figure B8: Plot 8 (CMT1-10-2)

Figure B9: Plot 9 (CMT4-5-2)

Figure B10: Plot 10 (CMT3-5-2)

Figure B11: Plot 11 (CMT2-5-2)

Figure B12: Plot 12 (CMT1-5-2)

Figure B13: Plot 13 (CMT4-5-4)

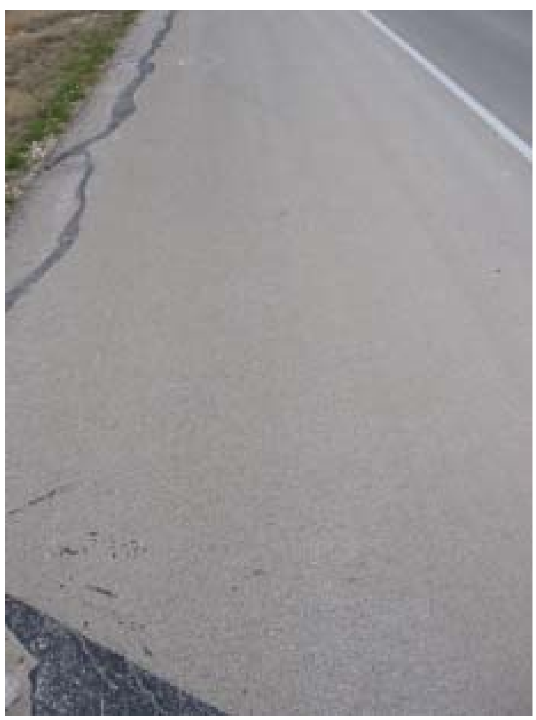

Figure B14: Plot 14 (CMT3-5-4)

Figure B15: Plot 15 (CMT2-5-4)

Figure B16: Plot 16 (CMT1-5-4)

Figure B17: Plot 17 (CP-10-4)

# Appendix C: Vegetation

Figure C1: Plot 1 (CMT4-10-4)

Figure C2: Plot 2 (CMT3-10-4)

Figure C3: Plot 3 (CMT2-10-4)

Figure C4: Plot 4 (CMT1-10-4)

Figure C5: Plot 5 (CMT4-10-2)

Figure C6: Plot 6 (CMT3-10-2)

Figure C7: Plot 7 (CMT2-10-2)

Figure C8: Plot 8 (CMT1-10-2)

Figure C9: Plot 9 (CMT4-5-2)

Figure C10: Plot 10 (CMT3-5-2)

Figure C11: Plot 11 (CMT2-5-2)

Figure C12: Plot 12 (CMT1-5-2)

Figure C13: Plot 13 (CMT4-5-4)

Figure C14: Plot 14 (CMT3-5-4)


Figure C15: Plot 15 (CMT2-5-4)


Figure C16: Plot 16 (CMT1-5-4)

Figure C17: Plot 17 (CP-10-4)

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