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16. Abstract

Compost materials have proven to be beneficial in mitigating shrinkage cracking at a Stephenville, Texas, site. However, the results are only valid for one soil type and related environmental conditions. In order to extend and verify the effectiveness of compost amendments in multiple soil types and climatic regions, an implementation study was conducted at three distinct test sites located in Lubbock, Bryan, and Corpus Christi regions, representing Panhandle Plains, Prairies & Lakes, and Gulf Coast regions of the state, respectively. Two locally available composts were considered for soil amendments at each site. A total of three test plots were constructed; one with no compost cover that served as a control plot and two with select compost amendments as covers. A compost amendment ratio of 20% by dry weight of soil was utilized in the previous research project. Both quantitative and qualitative data was collected from embedded moisture and temperature sensors, digital image surface cracking studies, surficial erosion surveys, and visual observations of paved shoulder cracking and vegetation growth. This data was analyzed with statistical comparison t-test, which indicated that both Dairy Manure and Biosolids compost amendments at Stephenville were yielding effective performance. Analysis of data from the new sites showed that both Biosolids Compost and Cotton Burr Compost amendments provided soil property improvements. Other compost plots, in particular those used in Bryan, did not provide satisfactory results due to lack of vegetation at the site, which resulted in high erosion and desiccation cracking. Composts that provided satisfactory performance were recommended for top soil treatments to control cracking on pavements. A few other recommendations include immediate seeding after CMT construction and use of a field compaction density equivalent to a lesser value of either 80-85% of standard Proctor maximum dry density or a bulk dry density of 87 pcf. These recommendations are made to enhance vegetation growth in order to control erosion and crack formation in subsoils and adjacent pavements.

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Field Studies to Address the Use of Compost to Mitigate Shoulder Cracking

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The researcher in charge was Dr. Anand J. Puppala, P.E., Department of Civil and Environmental Engineering, The University of Texas at Arlington, Arlington, Texas.

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Mr. James Parker (Stephenville Maintenance Section, Fort Worth District)
Ms. Sharon Barta, P.E., Ms. Sylvia Medina (RTI, Austin)

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INTRODUCTION AND RESEARCH OBJECTIVES

Soil cracking or shrinking has long been a problem for the Texas Department of Transportation (TxDOT) since these cracks allow intrusion of surface water into underlying soil and subgrade layers and hence weaken both. 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. Maintenance costs for these shoulder and highway distress problems are several millions of dollars statewide. This explains the need to stabilize shoulder subgrades in order to reduce the cracking resulting from the drying of subgrade soils.

A recent TxDOT research project (0-4573) had attempted to stabilize shoulder subgrades with composts by amending surface soils. Two types of composts, Dairy Manure Compost (DMC) and Biosolids Compost (BSC) were utilized for soil amendments. Field studies were conducted on State Highway 108 in Stephenville (Erath County), Texas, by constructing and monitoring seventeen (17) instrumented test plots. Test results showed that the biosolids compost amendment reduced shrinkage cracking of subgrades and hence mitigated new crack development on paved shoulders. The research was conducted on a clayey soil with low plasticity (CL) and hence the research results were valid for this soil type only. To extend and verify the effectiveness of compost amendments to other soil types of other districts, an implementation study was initiated.

This implementation study was conducted on three distinct test sites from different geographical regions which had different climatic conditions and soil types. These sites were located in Lubbock, Bryan, and Corpus Christi, representing the Panhandle Plains, Prairies & Lakes, and Gulf Coast regions of the state. Two locally available composts were considered for each test site. An attempt was made to select the composts similar to those used in the 0-4573 research and those that meet the TxDOT compost specifications. A total of three test plots were constructed at each site; one with no compost cover that also served as a Control Plot (CP) and two with two different types of compost amendments.

A successful completion of the implementation would not only verify the potential of compost amended soils in mitigating soil related cracking problems on pavement shoulders, but also provide an opportunity to enhance the soil with organics for vegetation growth and erosion control. This would also provide a cost effective and environmentally friendly solution since original sources of composts would be subjected to landfilling, incinerators and other disposal methods in Texas. The implementation study also involved the chance to understand the long-term performance of the compost amended soils and estimate the service life of these amended covers from the monitored data from the Stephenville site.

EXPERIMENTAL TESTING PROGRAM

Site Details

Figure 1 presents the locations of three new sites and the existing Stephenville site. These three new sites, Lubbock, Bryan, and Corpus Christi were selected because they have different soil types (with distinct PIs) and belong to different regions of Texas.

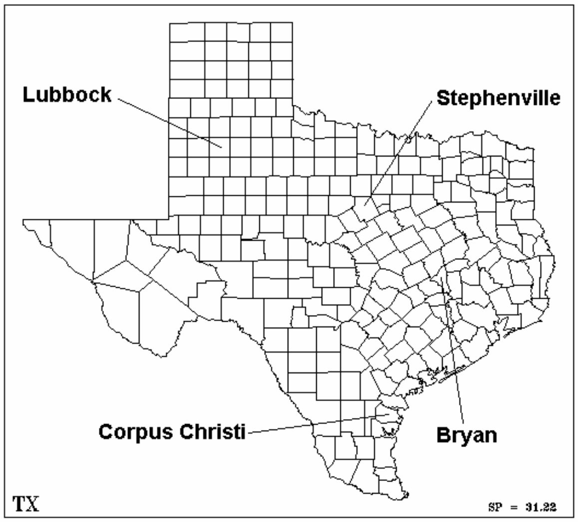


Figure 1: Locations of the test sites
(Source: Indiana State University)

Lubbock Site

The Lubbock site was located on US Highway 82, west of Crosbyton, (Crosby County), Texas. Two composts, Feedlot Compost and Cotton Burr Compost, were acquired from local sources and mixed with the control soil at 20% dry weight to form two types of Compost Manufactured Topsoils or CMTs. The local soil was classified as clay with low plasticity or lean clay (CL) per the Unified Soil Classification System (USCS) and as A-6 per the AASHTO classification.

Bryan Site

The Bryan site was located on FM 2818 about 2 miles north of State Highway 60 on the west side of the Texas A&M University. Two compost sources were used for the field studies, Biosolids Compost from the City of Bryan, Texas, and Wood compost from Conroe, Texas. The local soil was classified as lean clay or CL per the Unified Soil Classification System (USCS) and as A-6 per the AASHTO classification.

Corpus Christi Site

The Corpus Christi site was located on FM 188 east of Sinton, (San Patricio County), Texas. Cow Manure Compost and Biosolids Compost were used as soil amendments. The local soil was classified as CH or heavy clay per the Unified Soil Classification System (USCS) and as A-7-6 per the AASHTO classification. With January being in a wet season, it was difficult to thoroughly amend the soil with the compost. Therefore, construction during drier seasons are recommended.

Compost Source Materials

Compost is a disinfected and 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. Composting has the ability to improve the chemical, physical, and biological characteristics of soils. It should be mentioned that the same type of compost may have different properties due to the different feedstock material and process steps used during composting. The following sections describe different types of compost materials primarily used in the present implementation. Table 1 presents compost types used in each site.

Dairy Manure Compost (DMC), Feedlot Manure Compost (FMC), and Cow Manure Compost

All animal by-products can include manure and bedding from various animals. Compost produced from manures is known for possessing higher nutrient concentrations and is typically low in contaminants. When used appropriately, it improves biological activity and soil-chemical properties (Schmitt and Rehm, 1998). Bacteria and humus present in manure compost have the ability to increase microbial activity in the soil. This helps to improve the soil structure.

Biosolids Compost (BSC)

Biosolids are the nutrient-rich organic solid residue derived from residential, commercial, or pre-treated industrial wastewater processing. Biosolids are treated to reduce pathogens and contain only minimal levels of heavy metals and organic contaminants. Only biosolids that meet a “Class A grade” (exceptional quality) as outlined in the US EPA’s 40 CFR Part 503 regulations can obtain permits for general distribution (USCC, 2001). This material, after composting, is known as Biosolids Compost (BSC) and can be used for landscaping applications. BSC is also rich in wood fibers and hence provides natural soil modification.

Cotton Burr Compost

According to the National Agricultural Statistics Service (NASS, 2005), in 2004 all cotton production in the state of Texas was estimated at 7.85 million 480-pound bales. Depending on the harvesting and ginning equipment, the process of making one bale of cotton will produce from 0.2 to 0.35 ton of residue (gin trash) (Hilbers, 2003). Therefore in Texas, there was 1.57 to 2.75 million tons of gin trash produced in 2004. The cotton burr is slightly chunkier which helps loosen up the soil and retain water, therefore making it possible to use as a soil amendment. Figure 2 shows cotton fields near Lubbock, Texas.

Figure 2: Cotton fields near Lubbock, TX

Wood Compost

Wood wastes consist of tree trimmings, scrap wood, pallets, lumber, shipping containers, and construction wastes. Wood waste that cannot be used in its’ original form can be processed into a variety of products. These include compost for soil improvement, mulch for weed control, and wood chips for landscaping or trail stabilization. Wood that is composted makes excellent compost and soil amendments, which conserves water, reduces erosion, and lessens or eliminates the need for fertilizer (CIWMB, 2002).

Table 1: Compost used at Lubbock, Bryan, and Corpus Christi sites

Lubbock		**Cotton Burr Compost** **Organic Content 65%**		**Feedlot Manure Compost** **Organic Content 30%**
Bryan		**Biosolids Compost** **Organic Content 58%**		**Wood Compost** **Organic Content 68%**
Corpus Christi		**Cow Manure Compost** **Organic Content 18%**		**Biosolids Compost** **Organic Content 45%**

Site Soil Properties

At each site, soils from well known pavement distress sites were sampled and classified. The classification would ensure that different types of control soils with distinct PI properties were used.

Soil classification and basic properties of all four site soils including that of Stephenville are presented in Table 2. From the table, the tests showed a wide variation in the Plasticity Index (PI) property ranging from 14 to 47. The Lubbock soil exhibited the lowest PI value followed by the Bryan and then the Corpus Christi soils. A low PI value is attributed to a large amount of coarse sized soil particles in the control soil. A high PI value is attributed to the presence of finer materials (passing sieve No. 200) in the control soil.

Table 2: Soil classification and basic soil properties

Soil Properties	Stephenville	Lubbock	Bryan	Corpus Christi
Passing # 200 (%)	60.8	55.5	52.1	81.5
Liquid Limit	44	35	31	62
Plasticity Index (PI)	28	14	18	47
AASHTO Soil Classification	A-7-6	A-6	A-6	A-7-6
USCS Soil Classification	CL	CL	CL	CH

Basic and engineering tests were conducted on both control and compost amended soils. These tests included standard proctor compaction (Tex-114-E), organic content determination (ASTM D-2974-87), free swell (ASTM D-4546) and linear shrinkage (Tex-107-E) tests. Tables 3 to 5 present these test results.

Table 3: Test results of the control soil and CMTs from Lubbock

Property	Lubbock		
	Control Soil	Feedlot Manure Compost	Cotton Burr Compost
PI	14	10	8
Organic Content (%)	2.3	7.9	14.8
Dry Density (pcf)	123.5	103.3	93.3
Moisture Content (%)	9.9	16.3	18.9
Free Swell (%)	12.3	18.8	30.9
Linear Shrinkage (%)	7.0	4.0	5.0

Table 4: Test results of the control soil and CMTs from Bryan

Property	Bryan		
	Control Soil	Biosolids Compost	Wood Compost
PI	18	6	5
Organic Content (%)	4.2	15	17
Dry Density (pcf)	112.2	88.7	90.9
Moisture Content (%)	15.2	23.7	17.9
Free Swell (%)	1.7	4.8	21.4
Linear Shrinkage (%)	5.0	3.6	3.4

Table 5: Test results of the control soil and
CMTs from Corpus Christi

Property	**Corpus Christi**		
	Control Soil	**Cow Manure Compost**	**Biosolids Compost**
PI	47	28	33
Organic Content (%)	3.2	6	11.5
Dry Density (pcf)	104.4	98.1	91.5
Moisture Content (%)	15.9	20.3	21.9
Free Swell (%)	28.7	27.4	16.1
Linear Shrinkage (%)	18.0	16.1	15.9

CONSTRUCTION OF TEST SITES

At each test site, a total of three test plots (two with different compost amended soil covers and one with no cover) were constructed by following the design and construction methods of test plots developed from the 0-4573 research project. Each test plot was 50 ft long. A transition zone of 25 ft was used to separate the different plots in order to ensure that the adjacent compost materials did not affect the field results. Based on the recommendations from 0-4573 research project, a shoulder width of 10 ft and thickness of 4 in. were used in this study for all plots.

The specifications developed from the 0-4573 research project were first used to design the scarification subgrade depth, tilling depth, compost material to be spread over the tilled area, and the amount of water (in gallons) needed for the preparation of each test strip. After construction, all test sites were embedded with two moisture and one temperature probe. Two moisture probes were placed at 6 in. and 12 in. depths from the ground surface. The temperature probe was placed at a 6 in. depth from the surface. This sensor data was used to study the moisture content and temperature variations in subsoils. In addition, elevation surveys and digital images of the paved and unpaved shoulders were recorded for further analyses and comparisons.

DATA COLLECTION AND ANALYSES

This first part of the section is devoted to the analysis of the test results collected from the Stephenville site. This data was collected for almost three years providing data that could be used to explain the performance of the CMTs and possibly determine the service life of CMTs. The second part focuses on test results from the other three sites (Lubbock, Bryan, and Corpus Christi). As a part of the analysis, compost amended soils were evaluated for their moisture and temperature encapsulation capabilities, erosion and reductions in shrinkage cracking, as well as associated pavement cracking. Ranking analysis based on field performance was performed to determine the most efficient field application. Any problems experienced during the construction, data collection, and analysis were also addressed. The last part focuses on the potential cost benefits in terms of longer performance of pavements with reduced maintenance problems from cracked soils and pavements.

Methods of analysis used consisted of statistical analysis and visual observations. In most cases, questions were answered from statistical analyses using the comparison or 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. A p-value of 0.05 was used in the present analysis. This means that there is less than a 5% chance that the average values of treatment plots are not truly different from those of the control plot. Once significant differences in performance indices are found, 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 determined that the CMTs and Control Plot showed similar performance. In such cases, the plot performance and compost enhancements were still evaluated by assessing the variations in the magnitudes of performance index parameters.

Visual observation was used to compare the performance of CMT plots when magnitudes of performance indices could not be quantified or determined. Appearance of new cracks on the paved shoulders belongs to 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. The next section discusses results from the analyses of the Stephenville site data.

Stephenville Site

Temperature and moisture content data analyses

The softening or drying of the subgrade soils which support pavement structures often will result in cracking of pavements. The softening is the results from moisture intrusion coming from a cracked surface. The cracking develops from drying of the soil beneath the pavement. In order to prevent the surface along the pavement edge from being dried up, a compost amended soil was used as a cover material. The cover job is to retain soil moisture and prevent a soil surface from desiccating. To understand the effectiveness of the cover's material, moisture and temperature records were collected. For the cover material to be effective, the variations of moisture content and temperature in soil were expected to be fairly minimal or lower when compared with the variations of the control soil.

Volumetric moisture contents and soil temperature were continuously recorded from September 2004 to August 2005. Due to a shorter monitoring period than originally planned, the moisture and temperature variations were determined by calculating the differences between maximum and minimum sensor readings of every 15 days. This provided researchers a larger number of data points which resulted in a more reliable statistical analysis. Average values of these moisture variations over the entire duration of monitoring were also determined and these values were termed as the 'mean moisture variation' and 'mean temperature variation'. The moisture and temperature variation analyses were attempted by comparing both 'mean moisture variation' and 'mean temperature variation' of the test plots to the same of the Control Plot. Test results of the analyses are presented in Tables 6 and 7.

Due to the hydrophilic nature of composts, it was theorized that plots covered with compost amended topsoils would be able to retain moisture and therefore reduce moisture variations. However, from the moisture variation analysis, the moisture variation of the underlying pavement soils did not vary significantly when compared with the moisture variation of the Control Plot. The results show a similar trend as the results from the previous analysis collected during April 2003 to August 2004 (Puppala et al. 2005). Unlike the results of the moisture analysis, the temperature analysis showed an improvement in temperature variation. Most CMT plots had a reduction in temperature variation. This can be attributed to the ability of composts and also the vegetation to provide thermal encapsulation and hence preserved temperatures without large fluctuations at shallow depths. Hence, the composite section of compost amended top soil with vegetation served as 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 observed in the CMT plots.

Although the moisture analysis indicated that the Control Plot and CMT plots were not significantly different, another type of analysis was attempted by assessing the moisture variations in the test plots with respect to the initial compaction moisture content. Table 8 compares the initial compaction moisture content at the time of construction in each plot with the minimum moisture content measured from September 2004 to August 2005. Most compost plots with the exception of Plots 3, 8, 14, 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 by three points. It should be mentioned here that four out of five plots that experienced the most moisture losses were constructed with Dairy Manure Compost (DMC) covers. This indicates that this material possibly did not have the ability to retain moisture. Biosolids Compost (BSC), on the other hand, performed better in retaining the original compaction moisture content. This is attributed to the low organic content (6.4%) of Dairy Manure compost compared to that of Biosolids Compost (34%). The higher the organic content, the higher the ability of the material to attract and retain moisture.

Another comparison was also made on the moisture and temperature data (Table 9). The mean variations during April 2003 to August 2004 were compared to the mean variation during September 2004 to August 2005. The comparisons clearly showed the reduction of both mean variations in the last year of monitoring for all plots. This can be attributed to the thick vegetative cover developed from seeding at the site (Figure 3). The vegetations shielded the plot surfaces from direct exposure to heat and wind and therefore reduced the rate of moisture loss which was the main cause of the desiccation cracking.

Table 6: Analyses on ‘Mean Moisture Variations’

	Plot Name	**CP Mean**	**Plot Mean**	**t-value**	**df**	**p-value**	**Variation**
Stephenville **Moisture Content**	CMT4-10-4	10.26	7.71	1.5129	42	0.1378	Same
	CMT3-10-4	10.26	11.93	-0.9358	42	0.3547	Same
	CMT2-10-4	10.26	9.48	0.3466	32	0.7312	Same
	CMT1-10-4	10.26	8.70	0.8883	42	0.3794	Same
	CMT4-10-2	10.26	7.45	1.6820	42	0.1000	Same
	CMT3-10-2	10.26	8.96	0.7532	42	0.4556	Same
	CMT2-10-2	10.26	9.02	0.6568	39	0.5152	Same
	CMT1-10-2	10.26	13.65	-1.5284	42	0.1339	Same
	CMT4-5-2	10.26	13.13	-1.5073	40	0.1396	Same
	CMT3-5-2	10.26	10.92	-0.3756	42	0.7091	Same
	CMT2-5-2	10.26	7.42	1.6501	42	0.1064	Same
	CMT1-5-2	10.26	10.82	-0.3115	42	0.7570	Same
	CMT4-5-4	10.26	12.71	-1.3536	42	0.1831	Same
	CMT3-5-4	10.26	16.54	-2.8164	36	0.0078	Higher
	CMT2-5-4	10.26	10.40	-0.0605	38	0.9521	Same
	CMT1-5-4	10.26	5.26	2.8133	42	0.0074	Lower

Note : CP – Control Plot

Table 7: Analyses on ‘Mean Temperature Variations’

	Plot Name	CP Mean	Plot Mean	t-value	df	p-value	Variation
Stephenville **Temperature**	CMT4-10-4	14.60	13.09	2.2458	42	0.0300	Lower
	CMT3-10-4	14.60	8.08	10.7057	42	0.0000	Lower
	CMT2-10-4	14.60	9.56	7.0352	32	0.0000	Lower
	CMT1-10-4	14.60	11.77	3.6932	42	0.0006	Lower
	CMT4-10-2	14.60	16.94	-3.3722	42	0.0016	Higher
	CMT3-10-2	14.60	11.14	5.1891	42	0.0000	Lower
	CMT2-10-2	14.60	13.53	1.6095	42	0.1150	Same
	CMT1-10-2	14.60	N/A	N/A	N/A	N/A	N/A
	CMT4-5-2	14.60	10.52	6.0911	40	0.0000	Lower
	CMT3-5-2	14.60	14.18	0.5782	42	0.5662	Same
	CMT2-5-2	14.60	11.39	4.9024	42	0.0000	Lower
	CMT1-5-2	14.60	16.73	-2.9074	42	0.0058	Higher
	CMT4-5-4	14.60	20.64	-7.1268	42	0.0000	Higher
	CMT3-5-4	14.60	N/A	N/A	N/A	N/A	N/A
	CMT2-5-4	14.60	N/A	N/A	N/A	N/A	N/A
	CMT1-5-4	14.60	10.50	6.7254	42	0.0000	Lower

N/A – Sensor Failure; CP – Control Plot.

Table 8: Moisture content comparisons in control and test plots

Plot	Plot No.	Initial Moisture Readings @ 6 in. (Apr 2003)	Min. Moisture Readings @ 6 in. (Sep 2004-Aug 2005)
CMT4-10-4	1	14.31	14.71
CMT3-10-4	2	12.55	13.73
CMT2-10-4	3	22.55	14.31
CMT1-10-4	4	10	14.51
CMT4-10-2	5	12.35	15.10
CMT3-10-2	6	12.94	20.39
CMT2-10-2	7	17.45	20.39
CMT1-10-2	8	13.14	8.24
CMT4-5-2	9	11.96	15.88
CMT3-5-2	10	14.12	14.31
CMT2-5-2	11	11.76	15.29
CMT1-5-2	12	11.37	11.96
CMT4-5-4	13	12.35	12.37
CMT3-5-4	14	13.92	11.57
CMT2-5-4	15	18.04	14.90
CMT1-5-4	16	19.61	16.07
CP-10-4	17	16.86	13.53

Figure 3: Vegetation at Stephenville site (picture taken on June 25, 2005)

Table 9: Comparisons of mean moisture and temperature variations

	Mean Moisture Variation		**Mean Temperature Variation**	
	Apr 2003 Aug 2004	**Sep 2004 Aug 2005**	**Apr 2003 Aug 2004**	**Sep 2004 Aug 2005**
CMT4-10-4	12.77	7.71	15.57	13.09
CMT3-10-4	13.78	11.93	15.6	8.08
CMT2-10-4	11.63	9.48	15.18	9.56
CMT1-10-4	21.84	8.70	17	11.77
CMT4-10-2	12.68	7.45	19.56	16.94
CMT3-10-2	15.13	8.96	18.26	11.14
CMT2-10-2	17.35	9.02	21.43	13.53
CMT1-10-2	22.19	13.65	30.29	N/A
CMT4-5-2	15.8	13.13	24.88	10.52
CMT3-5-2	13.06	10.92	20.75	14.18
CMT2-5-2	14.4	7.42	17.82	11.39
CMT1-5-2	15.05	10.82	29.45	16.73
CMT4-5-4	16.75	12.71	23.25	20.64
CMT3-5-4	18.43	16.54	29.07	N/A
CMT2-5-4	14.54	10.40	17.32	N/A
CMT1-5-4	18.15	5.26	19.91	10.50
CP-10-4	15.34	10.26	22.71	14.60

Elevation surveys

According to the U.S. Department of Agriculture, the United States loses more than 2 billion tons of topsoil each year to erosion, mostly near the coastal regions. The detachment of topsoils can occur by the impact of rainfall or from flowing water. Damage from rainfall occurs when soil and sediment are carried away when rainwater slides down a slope and when water accumulates in drainage ditches along roads. The sediment accumulates in drainage ditches, resulting in lesser storage, and the result is flooding. The erosion can also cause deterioration underneath the pavement, which often results in collapsed roads (Storey and McFalls, 1997; Storey et al, 1998). The collapsed road is likely due to the moisture intrusion in the areas where there is a drop in shoulder, which could potentially lead to poor driving conditions and accidents (Figure 4).

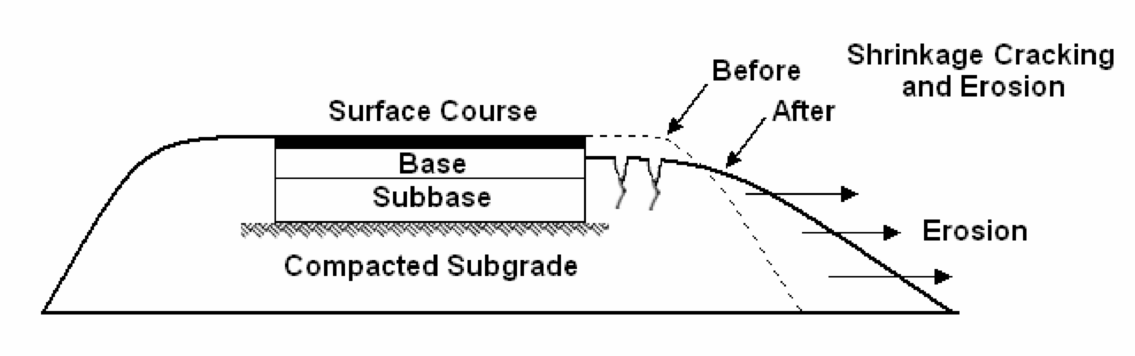


Figure 4: Collapsed shoulder due to erosion

Erosion also removes fertile soil rich in nutrients and organic matter which reduces the ability of plants and grass to establish, grow, and remain healthy in the soil. A reduction in plant growth and subsequent plant residue causes less soil cover allowing the erosion process to perpetuate and become worse (Risse et al., 2001). Therefore, controlling erosion is a key component in road and highway rehabilitation projects (Middleton et al., 2003). Compost amended soil provides a physical cushion-type of barrier between rainfall and the surface soil. Eroding forces from raindrops are dissipated as they hit the compost layer. As a result, less soil particles are dislodged. Compost amendment is also used to break up the heavily compacted soils and allow water to infiltrate the soil surface and therefore reduce surface runoff.

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 possible erosion of the plot. 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 five spikes set in both the longitudinal and transverse directions. 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 construction of the test plots in April 2003. 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. Figure 5 shows an elevation survey at the Stephenville site for the entire monitoring period (April 2003-August 2005).

Erosions were grouped by different CMTs and averaged to determine the final surface erosion. From the graph, there had been little erosion of the control and CMT plots since Aug 2004. This can be attributed to the vegetation establishment on every plot. Goldsmith et al. (2001) mentioned that vegetation generally helps to promote infiltration of water into soils. The process starts when raindrops are intercepted by vegetations, funneling water down stems, or allowing water to drip slowly off leaves rather than directly hitting the soil surface. Accumulated organic litter, combined with the roughness derived from living plant stems and foliage, helps to detain water, which might otherwise leave the area as runoff, thus increasing infiltration. Organic matter that becomes incorporated into the soils also improves the capillarity of soils and enhances water retention. Therefore, the erodability of the soil decreases as the infiltration, particle size, and the organic matter increase in the CMTs.

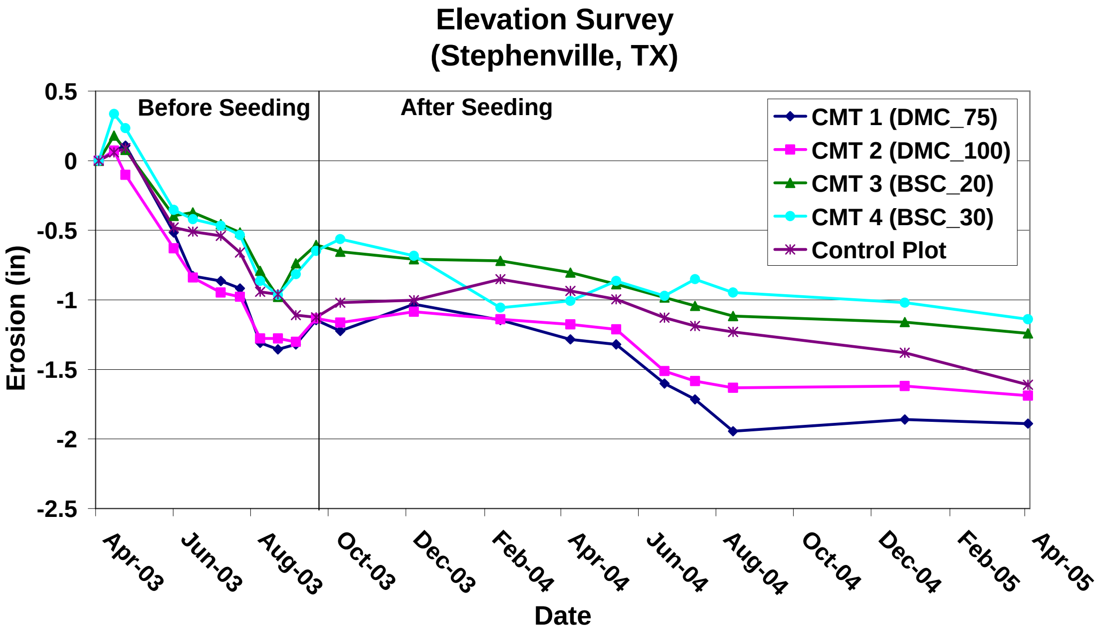


Figure 5: Elevation survey at Stephenville site

Paved shoulder cracking

As mentioned earlier, paved shoulder cracking can be attributed to the moisture intrusion into the adjacent shoulder subgrade layers due to either desiccation cracking and/or erosion. Therefore, less cracking on paved shoulders could be used to identify the CMT's effectiveness as an acceptable cover material. In order to distinguish between new and old cracks on the same pavement section, all the old cracks were crack sealed with bitumen at the beginning of 2005.

Figures 5a, 5b, and 5c present pictures of the same test plot 13, which were taken in 2004, at the beginning of 2005 and in August 2005, respectively. As the paved shoulder began to deteriorate, cracks would continue to appear and propagate as well as widen. Therefore, any cracks (Figure 5c) extending beyond the sealed parts (Figure 5b) would be considered new cracks.

Although the mean moisture and mean temperature variations showed an improvement from the last year, the cracking still occurred on the same test plots. These new cracks were possibly caused by crack sealant failure which resulted in moisture intrusion and softening of subsoils below the paved shoulder. As a result, the paved shoulder continued to deteriorate by forming new cracks as noted in Figure 7. Table 10 summarizes the results of visual observations of these images on all the test plots prior to and after crack sealing which supports the above observation.

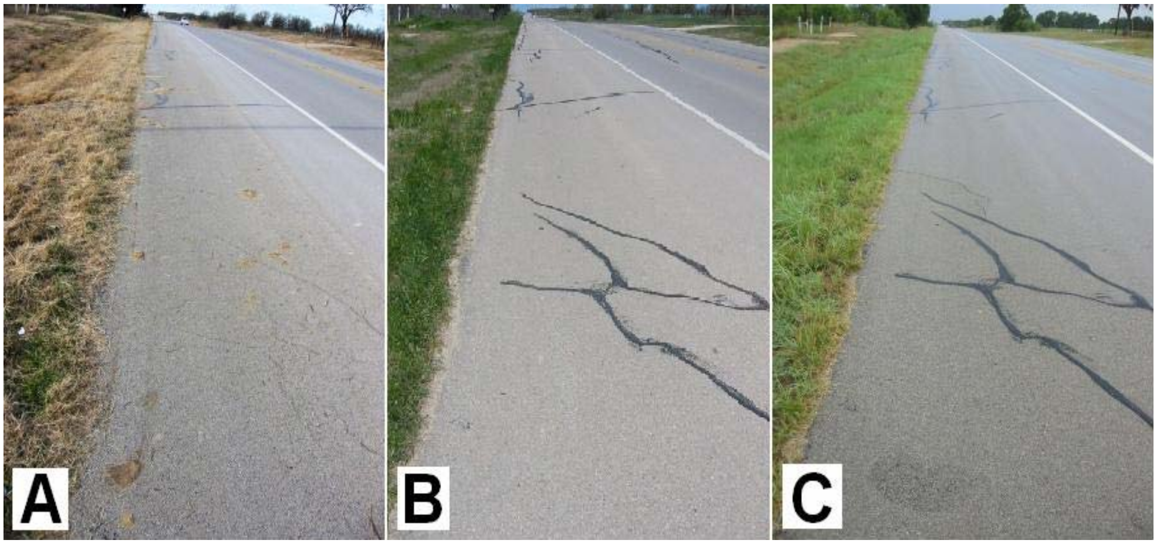


Figure 6: Pavement cracking on plot 13
(a) before sealant, 2004 (b) after sealant, early 2005 (c) new cracking, August 2005

Table 10: Visual observations of test plots

Plot Name	**Plot No.**	**Compost**	**Visual Observation (Before 2005)**	**Visual Observation (After 2005)**
CMT4-10-4	1	BSC	No new cracks	No new cracks
CMT3-10-4	2	BSC	No new cracks	No new cracks
CMT2-10-4	3	DMC	No new cracks	No new cracks
CMT1-10-4	4	DMC	No new cracks	No new cracks
CMT4-10-2	5	BSC	No new cracks	No new cracks
CMT3-10-2	6	BSC	No new cracks	**New cracks**
CMT2-10-2	7	DMC	No new cracks	No new cracks
CMT1-10-2	8	DMC	**New Cracks**	**New Cracks**
CMT4-5-2	9	BSC	**New Cracks**	**New Cracks**
CMT3-5-2	10	BSC	**New Cracks**	**New Cracks**
CMT2-5-2	11	DMC	**New Cracks**	**New Cracks**
CMT1-5-2	12	DMC	**New Cracks**	**New Cracks**
CMT4-5-4	13	BSC	**New Cracks**	**New Cracks**
CMT3-5-4	14	BSC	No new cracks	No new cracks
CMT2-5-4	15	DMC	No new cracks	No new cracks
CMT1-5-4	16	DMC	No new cracks	No new cracks
CP-10-4	17	-	**New Cracks**	**New Cracks**

Figure 7: Shrinkage of the asphalt concrete

Summary on Stephenville Site Data

The outcome of these analyses indicates that both Compost Manufactured Topsoils (CMTs) still provided satisfactory performance after 2.5 years of service in the field. The CMT plots showed similar moisture variations as the Control Plot and a reduction in temperature variation in the majority of the test plots. Eleven out of the sixteen CMT plots did not experience moisture content levels below their initial compaction moisture content after the construction.

Minimal erosions were measured on the CMT plots since August 2004 because of the thick vegetation cover which helped in reducing the eroding forces of raindrops, runoffs from pavements, and winds. Despite these enhancements, some plots still experienced new paved shoulder cracking. The majority of the paved shoulder cracking noted on the test sections are attributed to crack sealants applied on older cracks which appeared to perform poorly. As a result, new cracks around the old cracks started appearing within months after the crack sealant application. Overall, the shrinking behavior of subsoils was improved using CMTs which resulted in enhancing the service life periods of the paved shoulders and adjacent pavements with minimum maintenance problems.

In conclusion, both Biosolids and Dairy Manure Compost amendments are recommended for topsoil treatments to control moisture and temperature fluctuations in subsoils to reduce shrinkage cracking and erosion losses which are the critical factors in maintaining the integrity of a pavement. Addition of further fibrous materials in the form of yard trimmings or woodchips to dairy manure is expected to greatly increase the effectiveness of Diary Manure compost amendments.

One interesting observation from this site data is that after poor performance of the DMCs as CMTs immediately after test plot construction, they started to blend in well with the topsoil and thus started providing better encapsulation after the seeding process. This resulted in considerable improvements in moisture and temperature fluctuations and erosions as well as subsoil cracking and paved shoulder cracking.

Lubbock, Bryan, and Corpus Christi Sites

Temperature and moisture data analyses

Temperature and moisture variation analyses were performed in a similar way as the one performed for the Stephenville site in the earlier section. Volumetric moisture contents and soil temperature were continuously recorded from the time of construction till August 2005. The results of the analyses are shown in Tables 11 and 12. Since there are only two CMT plots in each new site, they were termed with their compost names in this report.

Table 11: 'Mean Moisture Variations' analyses of Lubbock, Bryan and Corpus Christi sites

	Plot Name	**CP Mean**	**Plot Mean**	**t-value**	**df**	**p-value**	**Variation**
Lubbock (Moisture)	Cotton Burr	9.29	8.38	0.4849	48	0.6300	Same
	Feedlot Manure	9.29	12.56	-1.4925	44	0.1427	Same
Bryan (Moisture)	Biosolids	12.09	15.67	-1.9753	40	0.0552	Same
	Wood Compost	12.09	14.21	-1.1090	40	0.2741	Same
Corpus Christi (Moisture)	Biosolids	13.48	11.94	0.3489	22	0.7305	Same
	Cow Manure	13.48	19.23	-1.1143	22	0.2772	Same

Table 12: 'Mean Temperature Variations' analyses of Lubbock, Bryan, and Corpus Christi sites

	Plot Name	**CP Mean**	**Plot Mean**	**t-value**	**df**	**p-value**	**Variation**
Lubbock (Temperature)	Cotton Burr	20.56	19.92	0.6215	48	0.5372	Same
	Feedlot Manure	20.56	16.11	4.4313	48	0.0001	Lower
Bryan (Temperature)	Biosolids	15.87	12.28	3.7480	40	0.0006	Lower
	Wood Compost	15.87	10.45	5.1507	40	0.0000	Lower
Corpus Christi (Temperature)	Biosolids	17.65	10.88	4.1035	22	0.0005	Lower
	Cow Manure	17.65	10.14	4.8721	22	0.0001	Lower

Trends similar to the ones at the Stephenville site were observed for most CMT plots. The moisture variations of the compost plots did not vary significantly when compared with the moisture variation of the Control Plot in the same site. Most of the CMT plots were able to reduce their temperature variations in the subsoils. Therefore, regardless of compost type, it was observed that composts have abilities to encapsulate thermally and therefore reduce temperature fluctuations. While the moisture variations were statistically the same, all manure compost plots experienced higher moisture variations. This is attributed to the inability of the manure CMT to significantly reduce desiccation cracking due to the lack of organic content (wood chips) resulting in the moisture to seep in and evaporate out with temperature changes.

The minimum moisture contents determined for data collected every two weeks were plotted in Figures 8 to 10. The minimum moisture contents of both compost plots at the Lubbock site did not fall below the initial compaction moisture contents whereas at the Bryan site, the control and biosolids plots experienced losses of 7% and 2% moisture content below their initial moisture contents, respectively. The Corpus Christi site was constructed on a rainy day and hence, all plots were unable to maintain the moisture levels which were higher than the initial compaction moisture content level. Although all plots at the Corpus Christi site experienced losses in moisture contents below the initial moisture content, both compost sections were able to retain more moisture during early February through early April. This indicates that compost materials used in this research were able to retain and sustain moisture and hence provided effective encapsulation of the surface.

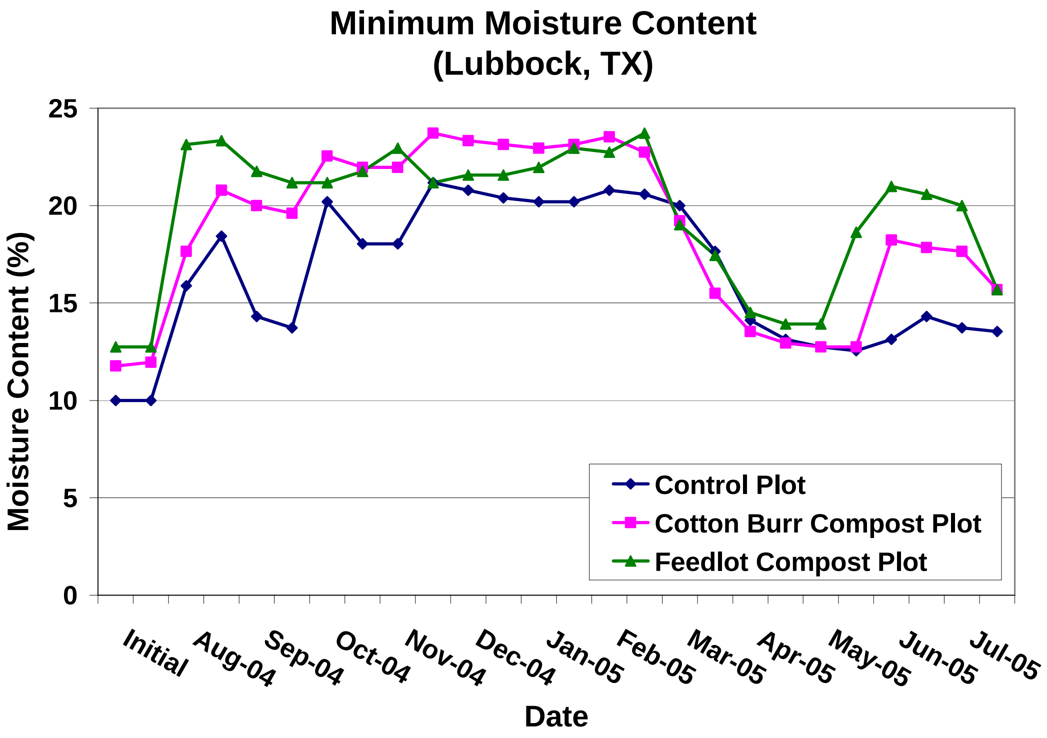


Figure 8: Records of minimum moisture content at Lubbock site

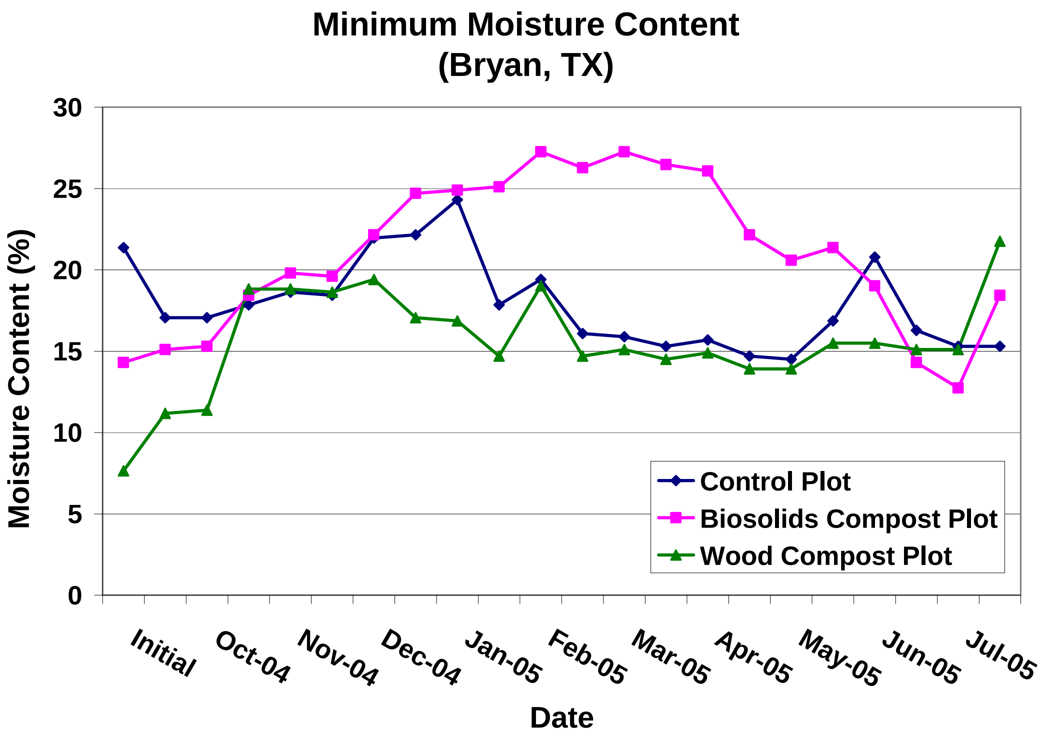


Figure 9: Records of minimum moisture content at Bryan site

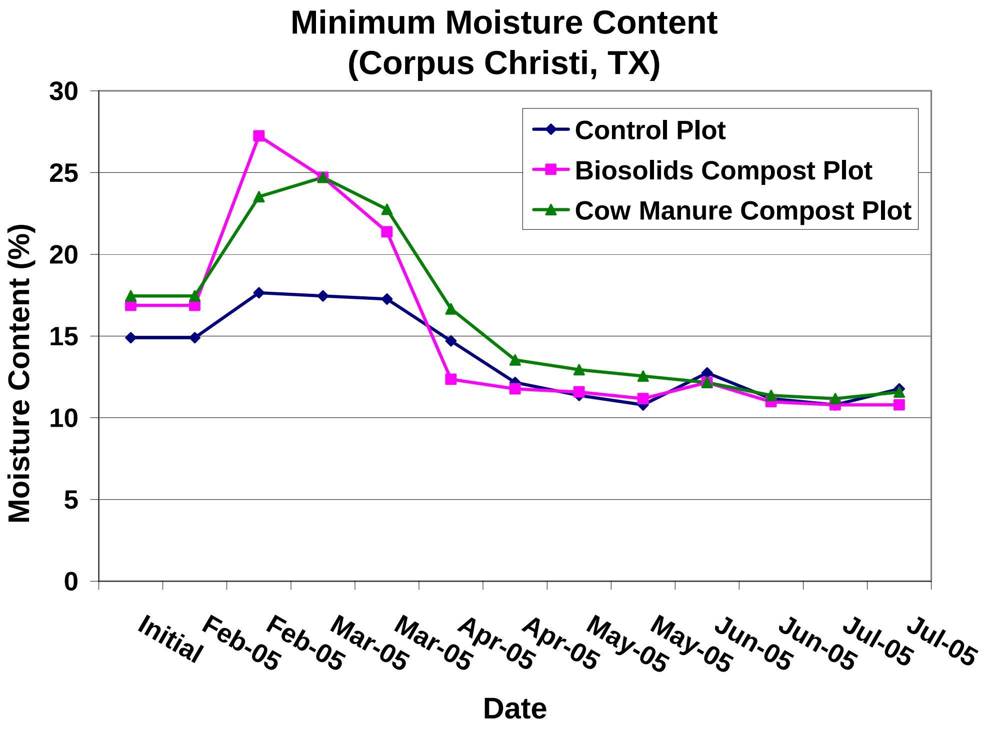


Figure 10: Records of minimum moisture content at Corpus Christi site

Elevation surveys

Elevation analyses were performed by comparing the elevation data of all three sections at all three sites. These results are shown in Figures 11 to 13. From Figure 11, it was observed that the erosions for the Cotton Burr Compost and the Control Plot of the Lubbock site were close to 0.65 inches. The highest erosion of 1 in. was recorded on the Feedlot Manure Compost plot. Manure Compost has been found to have a high rate of erosion. For the Bryan site (Figure 12), the erosions for the Control, Biosolids Compost, and Wood Compost plots were 0.85, 0.99 and 0.83 in., respectively. Vegetation growth observations indicated that the lack of vegetation in this site after construction increased the erosion rate. Figure 13 indicates a swelling nature of the control soil and the Cow Manure Compost, which are also noted in the laboratory results. Both plots experienced heaving during the wet season. The Biosolids Compost plot, on the other hand, only experienced erosion of 0.23 in. This indicates moderate surface erosion in this plot, most likely due to the lack of vegetation and lower organic contents of this material when compared to the one used in the Stephenville site.

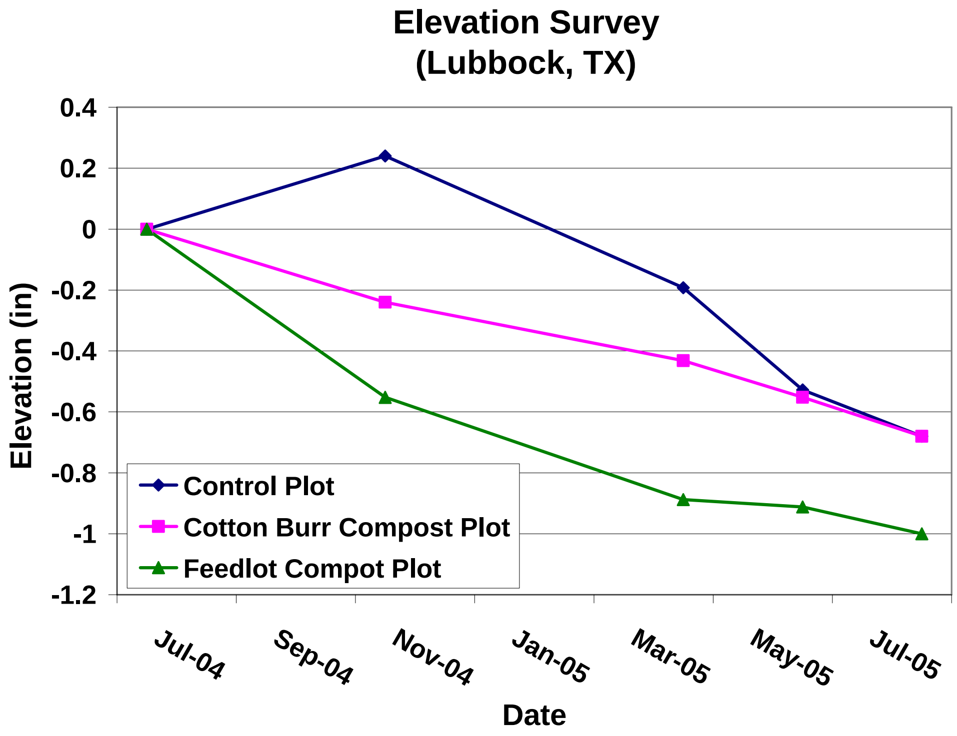


Figure 11: Elevation survey at Lubbock site

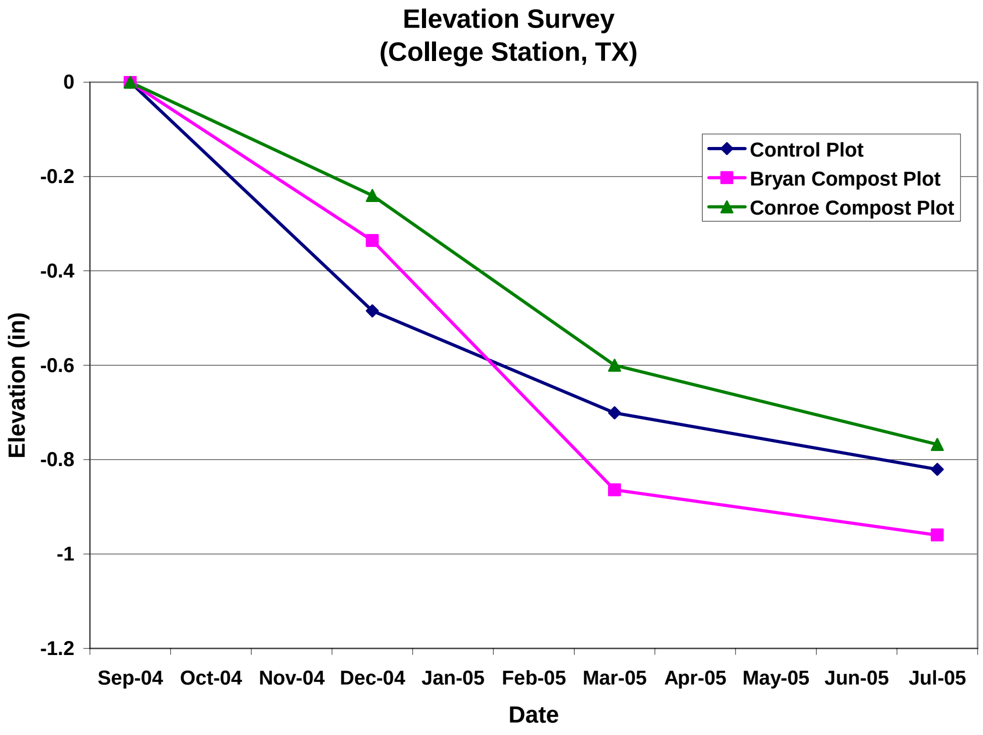


Figure 12: Elevation survey at Bryan site

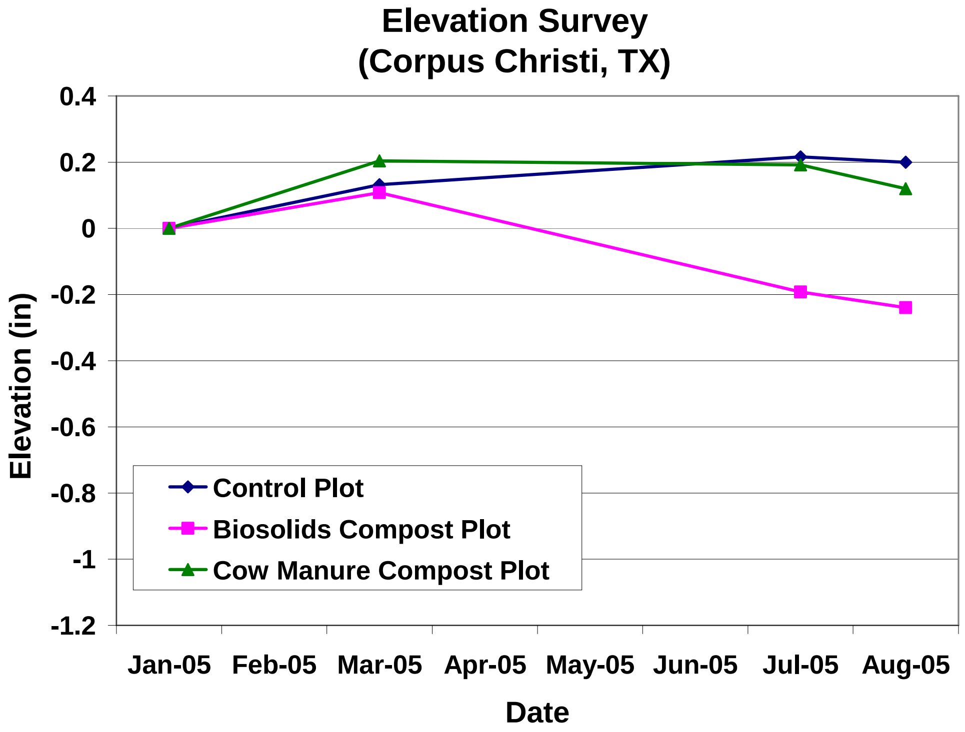


Figure 13: Elevation survey at Corpus Christi site

Shrinkage cracking analysis

As mentioned earlier, cracks often appeared on unpaved shoulder subgrades or in the CMTs where they were subjected to direct exposure of high temperature and wind. As a result, subgrade soils near shrinkage cracks will have moisture access during rainy seasons and will soften. Hence, it is essential to properly characterize the shrinkage strain potentials of natural and compost amended soils.

Table 13 presents the digital shrinkage analysis performed on the CMTs by randomly imaging the plot at different locations. Each image was analyzed using Scion image software to measure the areas under shrinkage. Shrinkage strains were calculated using the cracked surface to total surface area. Shrinkage strain values reported here were the average values of these random images. At the Lubbock site, the highest cracking (0.77%) was found on the control soil. The Cotton Burr Compost and Feedlot Manure Compost plots showed lesser cracking. This is because of the fibers in cotton burr and also the reduced PI of the compost amended soils. Hence, it can be concluded that the addition of composts at the Lubbock site was beneficial.

Due to the fibrous materials in both composts from the city of Bryan and Conroe, the application of compost at the Bryan site also reduced the amount of cracking. This also corresponded with the Linear Shrinkage test results. The Biosolids Compost plot at the Corpus Christi site also showed a reduction in shrinkage cracking. On the other hand, the application of Cow Manure Compost at the Corpus Christi site did not reduce the cracking. This demonstrated the test values of the highly plastic nature of the control soil and CMTs as seen in the laboratory test results. All three materials had high swell and shrinkage values.

Table 13: Shrinkage analysis of Lubbock, Bryan, and Corpus Christi sites

	Plot Name	Percent Cracking
Lubbock	Control Plot	0.77
	Cotton Burr	0.12
	Feedlot Manure	0.53
Bryan	Control Plot	0.39
	Biosolids	0.21
	Wood Compost	0.19
Corpus Christi	Control Plot	0.35
	Biosolids	0.13
	Cow Manure	0.41

Paved shoulder cracking

Visual observations of the pavement were studied. In order to distinguish between the new and old cracks on the adjoining pavement, the old cracks were first seal coated. Photos of the pavement shoulders were periodically taken and compared. Table 14 presents results based on the visual observations. Even though the minimum moisture content comparisons indicated that the Feedlot Manure Compost at the Lubbock site was able to retain water, the material was not able to significantly reduce desiccation cracking and erosion due to the lack of fibrous materials. Excess moisture was able to seep in through these cracks and the shoulder drop-off and therefore soften the subgrades. As a result, cracking was recorded on the Dairy Manure Compost plot at the Lubbock site.

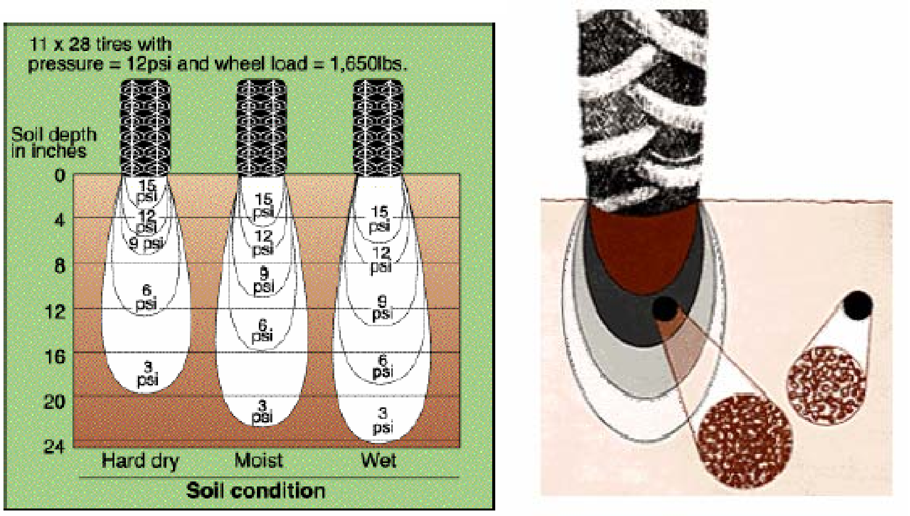
Despite the fibrous materials in the Biosolids and Wood composts at the Bryan sites, which have helped in reducing the amount of desiccation cracking at the Stephenville and Lubbock sites, the plots at Bryan still experienced paved shoulder cracking. This is attributed to high erosion in all the test plots due to lack of revegetation, which was close to 1 in. Moisture was able to seep into the pavement subgrade at the location where there was a drop of CMT shoulder material (due to surface erosion) as depicted in Figure 4. This leads to an important observation that both erosion control and desiccation cracking prevention should be addressed in order to mitigate paved shoulder cracking. The Corpus Christi site requires further monitoring to evaluate any further cracking of the paved shoulders.

Table 14: Pavement cracking of Lubbock, Bryan, and Corpus Christi sites

	Plot Name	**Pavement Cracking**
Lubbock	Control Plot	**New cracks**
	Cotton Burr	No new cracks
	Feedlot Manure	**New cracks**
Bryan	Control Plot	**New cracks**
	Biosolids	**New cracks**
	Wood	**New cracks**
Corpus Christi	Control Plot	No new cracks
	Biosolids	No new cracks
	Cow Manure	No new cracks

Vegetation Reestablishment

In any roadside construction, one of the eventual goals of this amendment is to allow native vegetation to grow naturally and permanently stabilize the soils in shoulders. Jurries (2003) reported that compacted soil stresses the root structure of newly planted vegetation. It makes it difficult for root penetration. Thus, newly established vegetation typically becomes stunted and remains smaller than vegetation established in undisturbed soil. Figures 14a and 14b show a localized compaction of soils from wheeled and tracked vehicles. The compaction can occur up to 30 in. below the soil surface. The amount of compaction is dependent upon compaction soil moisture content, soil type, and load distribution.



a b

Figure 14: A localized compaction of soils from wheeled and tracked vehicles (Jurries, 2003)

In this research, an attempt was made to visually determine how fast the vegetation was reestablished in each test plot. Digital photographic records showing the denseness of vegetation in each plot were collected and documented. Table 15 shows a visual observation of vegetation growth at the test sites. It should be mentioned that only scrapping and leveling off was performed on the control plots without compacting them. Hence, vegetation on the control plots was expected to recover faster.

At the Lubbock site, the Cotton Burr Compost plot was able to show the vegetation growth as soon as the control plot started showing the vegetation. This fast growth in the Cotton Burr Compost plot is attributed to the high organic contents of the compost, which provided nutrients to enhance the vegetation growth. Similar to the Stephenville site, the Dairy Manure Compost plot had lower vegetation. This is attributed to two factors; high field compaction densities and low organic contents of Dairy Manure Compost.

Both the Wood and the Biosolids Compost plots at the in Bryan site increased the organic content of the control soil from 4.2% to approximately 16%. This, however, did not result in the reestablishment of vegetation. Similar observation was noted even on the Control Plot, even after more than nine months after construction. Based on the targeted field densities, researchers believe that the heavily compacted soils of a few of the test plots retarded the vegetation growth. These plots include the Feedlot Manure Compost plot at the Lubbock site (dry density of 103 pcf) and both compost plots at the Bryan site (dry densities of 89 and 91 pcf) which are in the low PI classification. On the other hand, high densities of high PI clays of the Corpus Christi site did not show any vegetation growth related problems. Reasons for all these variations are explained in the following.

Table 15: Vegetation Reestablishment of Lubbock, Bryan, and Corpus Christi sites

	Construction Date	**Picture Taken On**	**Plot Name**	**Visual Observation**
Lubbock	July 20, 2004	Nov 20, 2004 (124 days)	Control Plot	Average
			Cotton Burr	Average
			Dairy Manure	Scarce
Bryan	Sep 17,04	Jul 2, 2005 (289 days)	Control Plot	Scarce
			Biosolids	Scrace
			Wood	Slight
Corpus Christi	Jan 27, 2005	Jul 2, 2005 (156 days)	Control Plot	Full
			Biosolids	Full
			Feedlot Manure	Full

Relf (1997) reported that highly compacted soils are very dense and lack pore space which lessens water holding capacity and rooting area. For growing plants, pore sizes are more important than total pore space. Therefore, plants will have a better environment in sandy soils if porosity is low because of the increase in water retention. The converse is true for clays. High porosity clays have a high macromovement, which provides high infiltration and more water available for plants. In general, a compaction between 80 and 85 percent of the standard Proctor maximum dry density optimizes slope stability with vegetation development and growth (Goldsmith et al., 2001). The bulk density should not exceed 87.4 pcf (1.4 g/cm^3) during dry condition, otherwise the root penetration is greatly retarded (Relf, 1997). This observation was valid for both low PI clays encountered at the Lubbock and Bryan sites. Construction of test plots at the high PI clay sites of the Corpus Christi site was performed during rain and hence, all test plots on this soil were able to quickly reestablish the vegetation. Possible softening of clays due to rains and high organic contents of the materials including composts and natural soil helped in the growth of vegetation. Overall, the researchers conclude that under the right soil compaction density, soil type, and compaction state or condition, the addition of composts result in quicker and healthier vegetation growth.

Final Recommendations

This section evaluates the overall performance of all the CMTs. The evaluation was 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 16. Since paved shoulder cracking indicated the ability of CMTs to protect the integrity of roadways, more importance was given to this observation. Hence, any plots with paved shoulder cracking should be reevaluated for future compost applications.

It can be noted that in the plot treated with the Cotton Burr Compost, both unpaved and paved shoulders performed satisfactorily with little or no cracking distress, respectively. Hence, Cotton Burr compost is recommended for future CMT applications. Though the Feedlot Manure Compost plot in Lubbock and both Compost plots in Bryan were able to reduce desiccation cracking to a certain extent, the high erosion rate of these materials allowed extra moisture to infiltrate into the subsoil layers and weaken them. The softening of the subsoil layers further caused paved shoulder cracking. For this reason, Feedlot Manure Compost from the Lubbock site and both composts at the Bryan site are not recommended unless seeding is implemented immediately without any delays.

Table 16: Evaluation and recommendation of CMTs of Lubbock, Bryan, and Corpus Christi sites

Location	**Plot Name**	**Enhancement?**						**Final Recommendation**
		Shrinkage (%)	**Temp Variation (Fo)**	**Moisture Variation (%)**	**Erosion (in)**	**Paved Shoulder Cracking**	**Vegetation**	
Lubbock	**Control**	**0.77**	**20.56**	**9.29**	**0.67**	**Yes**	**Average**	
	Cotton Burr	**0.12**	**19.92**	**8.38**	**0.68**	**No**	**Average**	**Yes**
	Feedlot Manure	**0.53**	**16.11**	**12.56**	**0.99**	**Yes**	**Scarce**	**No**
Bryan	**Control**	**0.39**	**15.87**	**12.09**	**0.85**	**Yes**	**Scarce**	
	Biosolids	**0.21**	**12.28**	**15.67**	**0.98**	**Yes**	**Scarce**	**No**
	Wood Compost	**0.19**	**10.45**	**14.21**	**0.83**	**Yes**	**Slight**	**No**
Corpus Christi	**Control**	**0.35**	**17.65**	**13.48**	**0.19****	**No**	**Full**	
	Biosolids	**0.13**	**10.88**	**11.94**	**0.24**	**No**	**Full**	**Yes**
	Cow Manure	**0.41**	**10.14**	**19.23**	**0.13****	**No**	**Full**	**Yes***

Note: * - Requires longer monitoring period; ** Swelling was observed

The failures at the Bryan site probably resulted from lack of vegetation which resulted in erosion and hence new cracks in the pavements. The addition of the Biosolids Compost at the Corpus Christi site was able to enhance the quality of the existing soil and resulted in no paved shoulder cracking. Therefore, Biosolids Compost is recommended for that particular soil type and climatic region. A longer monitoring period is needed for the researchers to evaluate the performance of the Cow Manure Compost.

FUTURE COST ANALYSIS

The application of CMT in mitigating desiccation cracking has already been proven to be successful. However, the initial construction cost is often higher when compared to the traditional roadside shoulder construction and management (crack sealing). This is a result of a higher material transportation cost and the lack of proper equipment for working in sloped shoulder sections. While the initial cost is high, the annualized life cycle cost is lower due to the longer project life, lower maintenance cost, and less environmental impact. Therefore, the life cycle cost, (analysis) of this project must be considered.

This part of the study is focused on a cost analysis of the application of CMT in mitigating desiccation cracking. The objective is to determine if this method, over the long run, is a more economical alternative to traditional roadside management. Traditional roadside management was used as a base line in this analysis while the application of CMT was considered as an alternative. As this analysis is based on comparison, costs were determined for the traditional method as well as for the CMT method. Since CMTs were implemented at the selected sites, actual costs could be applied. Estimated traditional treatment costs were determined for comparison. Figure 15 illustrates the concepts of life cycle costs for CMT and traditional methods and also a potential saving.

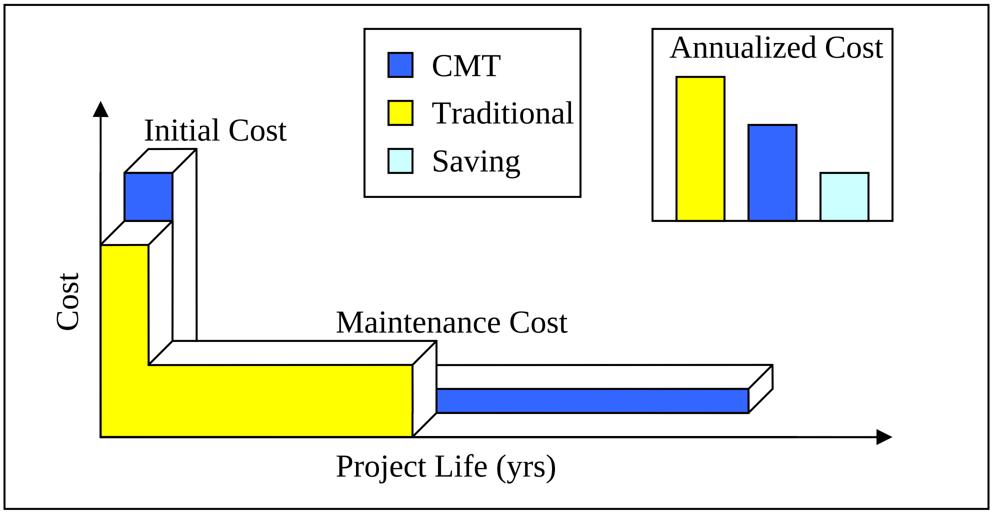


Figure 15: Cost comparison between traditional and CMT methods

Projected Life Period

Total project cost usually consists of capital cost as well as costs for maintaining the stability of roadways throughout the design life. The CMT method, if effective, would require less projected maintenance costs through the mitigation of subsoil crack initiation and propagation through the pavement materials. It should also be noted that cracked pavements are considered unattractive from an aesthetics point of view.

Table 17 summarizes the probable annualized costs’ analysis for the project based on a design life of M years for traditional treatment and N years for CMT. The initial cost consists of site investigation, construction, equipment, materials, labor, traffic control, seeding, roadside cleanup, administration, and contingency. Maintenance cost consists of site improvement, mowing, reseeding, and erosion control. The total cost is the initial cost plus the total maintenance costs. Annualized cost is an average cost for the entire project length.

Table 17: Calculation of annualized cost for design life

	Traditional	**CMT**
Design Life (yrs)	M	N
Initial Cost ($)	X_1	X_2
Maintenance Cost ($)	Y_1 for every A years	Y_2 for every B years
Number of Maintenances	C = The number before decimal point of M/A	D = The number before decimal point of N/B
Total Cost ($)	$X_1 + CY_1$	$X_2 + DY_2$
Annualized Cost for Design Life ($)	$(X_1 + CY_1)/M$	$(X_2 + DY_2)/N$

The cost analysis may show that the use of compost as a soil amendment is expected to be more economical over the long run. It allows an understanding of the benefits of using compost in roadside maintenance from a cost perspective. Figure 16 presents the probable accumulated costs over the service period. The type of graph allows an estimate for the payback period for investment. This analysis needs an accurate estimation of the service or projected life of the compost treatment which is expected to be beyond 2.5 years based on the monitored data of the Stephenville site. Better estimation of this time period will allow a comprehensive cost analysis of the CMT treatments which in turn will provide better cost effectiveness of the compost treatments for mitigating cracking on pavements.

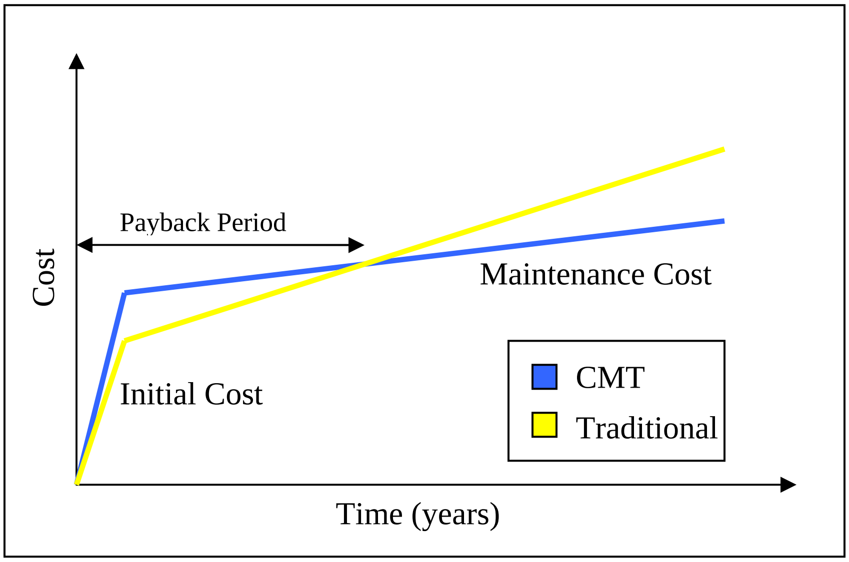


Figure 16: Accumulated costs over the design life

Overall, further monitoring of the compost treated sections of the Stephenville site in particular would provide better estimation of service periods of the compost treatments allowing better cost benefit calculation of such treatments. Other benefits are also expected from such analysis, which are presented in the following:

- The longer the amended covers can last, the higher the cost savings of highway maintenance projects will be.
- Environmental benefits from using composts in roadside construction and maintenance are paramount since solid wastes from which composts are made will be detrimental to both humans and the environment.

- Landscaping around highways in Texas will be enhanced and pavement aesthetics will be improved.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The following presents a few salient conclusions based on the field studies and monitoring conducted at the four test sites:

1. Based on the comprehensive field data collection and analysis from the Stephenville site, both Biosolids and Diary Manure CMTs provided effective moisture and temperature encapsulation with pavement crack mitigation for 2.5 years of service life. It should be mentioned here that the compost amended soils can last longer than 2.5 years provided seeding at the sites and turf growth were established early at the sites after construction. Further monitoring of the Stephenville site plots beyond 2.5 years will lead to better estimation of service life.
2. Based on the districts sites' data and analysis, it can be mentioned that both Biosolids Compost and Cotton Burr Compost amendments provided the best expansive soil property enhancements. This effectiveness was verified by several types of data collection from field studies, including moisture and temperature variations, digital image analyses of subsoil shrinkage cracking, and visual observations of paved shoulder cracking and vegetation growth.
3. Though a lower proportion of Dairy Manure and Cow Manure Composts were used in this research, the lack of fibrous materials and organic content in them might have lessened their performance in the amended soils. The addition of natural fibrous material to the original feedstock and immediate seeding at the site will enhance the performance of these materials by reducing erosion problems of these materials.
4. Dairy Manure Compost sections at the Stephenville site, which showed poor performance in the first year after construction, started providing better and more stable support by minimizing moisture and temperature fluctuations, less erosion, and enhanced vegetation growth. Existing pavement cracks at the site followed by crack seal failure has initiated further cracking through subsoil related soil movements. This leads to an important assessment that future site selection should use new pavement construction sites, if possible. Such use will eliminate the cracks formed due to the moisture intrusion from the existing cracks.
5. Both Wood and Biosolids compost types used at the Bryan site did not provide effective treatment of shoulder subsoils primarily due to their performance with respect to erosion. This erosion eventually subjected these CMTs to cracking within months after compost treatment.
6. From the analyses, erosion and desiccation cracking controls are the two most important factors to prevent overall paved shoulder cracking. In order to accomplish these two factors, researchers recommend the following
    - Immediate seeding to prevent surface erosion loss
    - Select compost with high to moderate organic content (nutrients) to promote vegetation growth
    - Addition of natural fibrous materials (woodchips or yard trimmings) to Dairy Manure feedstock to reduce desiccation cracking
    - Field compaction density should be lesser of 80-85% percent of the standard Proctor maximum dry density or a bulk density less than 87 pcf in dry condition to facilitate vegetation growth

In summary, by using composts in roadside shoulder maintenance, TxDOT can greatly reduce the amount of organic wastes going into landfills and help in maintaining the pavement surface performance and aesthetics.

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