EVALUATION OF ORGANIC MATTER ADDITION AND INCORPORATION ON STEEP CUT SLOPES

Phase I: Literature Review and Potential Applicable Equipment Evaluation

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16. Abstract

Erosion of steep highway cut slopes in Montana is the consequence of poor vegetation development in nutrient-poor growth media resulting from highway construction where topsoil cannot physically be replaced due to slope steepness. A literature review was conducted to synthesize available examples of compost application and incorporation on steep cut slopes to stimulate vegetation growth and retard erosion. Equipment applicable to either compost application or incorporation on slopes steeper than 3(H):1(V) was identified. Candidate research test plot locations were evaluated and are described.

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1.0 Introduction

1.1 Problem Statement

Fundamental to successful revegetation of highway corridors following disturbance is the creation of a growth environment conducive to the establishment and early survival of the seeded plants. Steep cut slopes present a unique problem. The steepness of the cut slopes prevents practical replacement of salvaged topsoil with conventional equipment. The current remedy is simply to broadcast seed and hydro-mulch the bare slope. These techniques all too often result in marginal plant establishment since germination and initial seedling survival is limited by nutrient poor, rocky substrates characteristic of cut slopes. The resulting poor vegetation establishment leads to increased erosion and sedimentation, occasional slope failure, increased noxious weed growth, and low aesthetic quality. All of these factors except the latter can be expected to substantially increase maintenance costs in the affected areas.

1.2 Experimental Hypothesis

The benefits of soil organic matter are widely known and have been shown to produce significant positive responses in vegetation performance when applied both as surface top dressing and shallow incorporation into the substrate profile. Organic matter is a critically important attribute of the soil environment, contributing or responsible for enhanced water infiltration, nutrient availability, water holding capacity, mycorrhizae development, and improved soil structure. Amendment of steep cut slopes with organic matter may lead to improved vegetation condition, decreased erosion, and reduced maintenance cost.

Phase I of this research project consisted of two primary tasks: 1) a review of literature to determine probable optimum rates of organic compost addition to steep cut slopes, and 2) evaluation of potential equipment capable of applying and incorporating the compost to a maximum of 10.1 cm (4 in.) on 2H:1V slopes. Site reconnaissance of candidate field research sites for the second phase of the project also occurred.

Phase II of this project will consist of two primary tasks: 1) evaluation of the efficacy of the application/incorporation equipment, and 2) qualitative measurement of vegetation condition and observations of erosional stability. Construction of experimental plots at three field sites are anticipated during Phase II, which will consist of a site on high clay soils in southeastern Montana, and sites on glacial till and coarse valley fill alluvium in northwestern Montana. Site maps are located in Appendix A. Phase II is anticipated to be conducted over a three year period beginning in summer 2003.

2.0 Methods

The Reclamation Research Unit was contracted by the Montana Department of Transportation to conduct a research investigation evaluating the effects of compost addition to steep cut slopes. This project has been split into two phases. The first phase was a literature review and equipment evaluation, and is the subject of this report. The second phase is anticipated to be construction and monitoring of experimental plots.

A Technical Advisory Panel has been created using compost and revegetation expertise found in State government and the private sector. The Technical Panel has and will continue to provide input on experimental design, monitoring and issues that affect the research outcome.

A literature review was performed utilizing a variety of information sources. State Departments of Transportation across the U.S. were queried for their experience in conducting similar work. A number of responses were solicited and used to guide subsequent phone calls and e-mails. Several larger research studies were identified that used compost on highway slopes. Authors of the larger investigations were contacted directly to obtain research reports, updates occurring since publication of reports and follow-up contacts. On-line searching also revealed numerous trade journal articles related to highway revegetation using compost. Photocopies of trade journal publications were also received from Montana compost producers. Limited technical information was identified in the peer-reviewed scientific literature.

A review of applicable equipment for use in applying and incorporating compost on steep slopes was conducted in parallel with the literature review. The equipment used for incorporation of compost on steep slopes was poorly reported in literature, primarily since compost incorporation on steep slopes appears to occur infrequently. Effort was subsequently made to contact equipment vendors and contractors directly to identify equipment that could be put to use on steep slopes. Several potential contractors or vendors were found with relevant experience or equipment.

Site reconnaissance of candidate research sites was performed to focus the equipment selection task and to prepare for initiation of phase II. A northwest Montana highway construction project was visited on May 7, 2003 by University, MDT and Technical Panel representatives. This project was constructed several years ago along U.S. Highway 2 west of Happy's Inn. Steep, erosive cut slopes were frequently observed. Two candidate research sites were identified. A south-facing alluvial rock slope was identified with very limited vegetation cover. Erosion from this site was minimal. This site is identified in the following text as Elk Creek Road. A second south-facing candidate research site was identified near-by on glacial till parent material. This steep-slope research site was severely eroded and poorly vegetated. This site has been named Milepost 67.

3.0 Results

Principal tasks identified in the Phase I proposal were review of the compost application on steep slope literature and identification of equipment capable of incorporating compost on steep slopes. The findings of these investigations are reported in Section 3.0 of this report.

3.1 Literature Review

A literature review was conducted to identify relevant examples of compost treatment of steep cut slopes. An on-line search was conducted to identify sources of information in the peer reviewed or trade literature. Written reports were identified and supplemented by personal contacts with Department of Transportation professionals across the country with similar issues and expertise. In parallel with the sources of information evaluated, the following literature review is split into two primary sections. The first section summarizes the findings of research investigations evaluating various aspects of compost treatment of disturbed sites and the body of literature that demonstrates the effectiveness of compost addition. The second section reports the core case studies conducted by Departments of Transportation within the U.S. that specifically evaluated compost application to cut slopes. The core case studies are provided by Departments of Transportation from California, Connecticut, Idaho, Iowa and Texas.

3.1.1 Research Investigations

3.1.1.1 Introduction

Composting is the controlled biological process of decomposition and recycling of organic material into a humus rich soil amendment known as compost *(1)*. Compost has a variety of uses and studies have shown that compost can improve soil quality and productivity as well as decrease and control erosion. Compost blankets and berms have become increasingly popular for controlling erosion and enhancing plant establishment at construction sites. These blankets and berms are preferred by many contractors because they can be left in place following construction and not only aid in the control of erosion, but supply benefits to the soil *(2)*.

A project funded by the U.S. Environmental Protection Agency (USEPA), The Composting Council Research and Education Foundation (CCREF) and the U.S. Composting Council (USCC) resulted in a document that describes several State Department of Transportation projects involving compost *(3)*. A summary of compost use by each State DOT is also included in the document. This document states that compost has the unique ability to improve the properties of soils physically (structurally), chemically (nutritionally), and biologically. In addition, research and field experience have documented that vegetation established with compost grows healthier and faster, and is better able to persist in harsh conditions.   Compost also has the ability to aid in the control of erosion and decrease sediment loss from slopes.

> "Various research, as well as, field trials, have shown that compost can often out-perform conventional slope stabilization methods, such as hydro-seeding, hay/straw mulching, geotextile blankets, etc. Compost, composted mulches, and compost blends are used as a soil blanket or cover, and typically placed on up to a 2H:1V slope at an application rate of 5 cm to 10 cm (2 – 4 in). Lesser applications rates are possible in areas of lower flow and on less severe slopes. This compost layer not only absorbs the energy of the rainfall, which causes the movement of soil particles, but can also absorb a substantial volume of moisture, as well as reduce its flow velocity, improving moisture percolation into the soil. These soil blanket products are typically applied using a bulldozer, grading blade, or pneumatic blower. The courser or woodier compost used in erosion control are often not seeded following application but may be seeded at a later time, once the product stabilizes." *(3)*

The benefits of compost are reported and substantiated in numerous articles, reports and publications. Table 1.0 lists of some of the recorded benefits of compost.

Table 1.0. Benefits of compost addition identified by various investigators.

US Composting Council *(4)*	**US EPA** *(5)*	**Mitchell, D.** *(6)*	**Univ. of Georgia** *(1)*	**Univ. of Florida** *(7)*
Improves soil structure, porosity, bulk density	Add organic bulk and humus to regenerate poor soils	Improvement of soil	Increases water infiltration into the soil surface	Increases water retention in sandy soils
Increases infiltration and permeability of heavy soils, reducing erosion	Helps suppress plant diseases and pests	Improvement of plant growth	Reduces runoff and soil particle transport in runoff	Enables soil to hold more plant nutrients (increased CEC)
Improves water holding capacity in sandy soils, reducing water loss and leaching	Increases soil nutrient content and water retention in both clay and sandy soils	Addition of organic matter	Increases plant growth and soil cover	Provides small amounts of plant nutrients to the soil/plant system
Supplies a variety of macro and micronutrients	Restores soil structure after microbe reduction by chemical fertilizer	Addition of nutrients	Reduces soil particle dislodging	Reduced soil bulk density and increases total pore space
Controls or suppresses certain soil-borne pathogens and nematodes	Combats specific soil, water, and air problems	Addition of microbial populations	Increases water holding capacity of soil	Helps moderate soil temperatures

US Composting Council *(4)*	**US EPA** *(5)*	**Mitchell, D.** *(6)*	**Univ. of Georgia** *(1)*	**Univ. of Florida** *(7)*
Supplies significant quantities of OM	Prevents pollutants in stormwater runoff from reaching water resources	Effective erosion control	Buffers soil pH	In some cases, reduces soil borne diseases
Improves CEC of soils, improving their ability to hold nutrients		Slope stabilization	Alleviates soil compaction by increasing soil structure	Suppresses the population of certain nematodes
Supplies beneficial microorganisms		Reduction in use of chemical fertilizers	New vegetation can establish directly into compost	Positive effect on soil microbial populations.
Improves and stabilizes soil pH				
Can bind and degrade specific pollutants				

The following paragraphs summarize several articles and reports regarding the use of compost to control erosion and establish vegetation. The format of this literature review separates these summaries into several sections based on specific areas of interest. These areas are vegetation, erosion, application, equipment, and parent material. The articles and reports reviewed describe methods and results of demonstration projects and personal experience using compost for vegetation establishment and erosion control. No articles were identified that describe incorporating compost into the underlying soil layer on slopes that were 3:1 or steeper; on these types of slopes, compost was either blown into place using a pneumatic blower or spread by hand.

3.1.1.2 Vegetation

Compost has been viewed as a valuable soil amendment for centuries *(5),* and is considered an effective way to improve soil conditions and enhance plant establishment and growth *(5, 8, 6).* Studies and demonstrations have shown compost to be more effective than traditional hydro-mulch at establishing turf because compost forms a thicker, more permanent growth due to its ability to improve the infrastructure of the soil *(5).* In addition, compost blankets shade the soil and help to control weeds when planting groundcover *(7).*

A publication distributed by the USEPA *(5)* summarizes a compost study in a suburb of Washington D.C. Test plots were located on a 2H:1V and a 3H:1V slope. A hydro-mulch/fertilizer treatment was applied to some plots and a 6.4 cm (2.5 in) layer of compost was spread on the other plots. Half of the composted plots received a small amount of fertilizer. Fescue grass seed was applied and a thin layer of compost was then added to conceal the seed from birds. Results of the project revealed that compost used alone produced better results than either of the areas treated with hydro-mulch or the area treated with compost/fertilizer (growth in the compost/fertilizer plot was superior to that found in the hydro-mulch/fertilizer). While the areas with the hydro-mulch/fertilizer combination showed quick initial vegetation growth, the areas treated with only compost matured within 6 months, out-performing the traditional method by establishing a thick, healthy vegetative cover.

Iowa State University completed a report summarizing a three-year study sponsored by the Iowa Department of Transportation in April 2003 *(9)*. Three types of compost were used for the demonstration. These three compost types were spread on the test plots at two depths 5 cm and 10 cm (2 in and 4 in). Another plot was covered with a topsoil treatment which consisted of a 15 cm (6 in) blanket of topsoil over underlying soil. None of the materials were incorporated into the underlying soil. The results indicated that although the compost plots generally had coarser textures and lower densities than soil, they produced as much vegetation as the topsoil or compacted subsoil (significantly equivalent among all treatments). In addition, areas that were treated with compost blankets exhibited significant suppression of weed growth. The total mass of weeds harvested from the compost treated plots at the end of two growing seasons was less than one-third of the weed growth on the topsoil treated and untreated plots. It was also noted that the depth of the compost treatment was not a significant factor. Although there was not a significant difference in vegetation growth; weed control, erosion, and sediment control were enhanced in the composted plots.

Another large-scale erosion control project was initiated by the Connecticut Department of Transportation (ConnDOT) *(10).* Eight test cells (3 m W x 10.7 m L) were prepared with different surface treatments including an untreated reference cell and a standard ConnDOT hay and seed preparation. These cells were located on a slope of 2H:1V. Most soil surface treatments used on construction projects by ConnDOT have the long-term objective of growing grass. ConnDOT requires that 100 plants per square foot be established in a treated area. Three of the eight experimental cells used for this project were seeded according to ConnDOT specifications. Grass germination in these cells was checked by counting from three areas of one square foot picked by random number coordinates in each cell during Fall, 1997. The results showed that all of the treatments supported sufficient grass growth to pass the ConnDOT requirements. The ConnDOT report conclusions stated that the cells with compost treatment that were seeded produced turf that exceeded the ConnDOT minimum specifications *(10).*

The methods used for applying seed mixes when using a compost blanket varied among the literature reviewed for this report. One method that is becoming increasingly popular is mixing seed with the compost and then using a pneumatic blower to place the compost/seed mixture onto the ground. The Oregon DOT completed an erosion control project in which a pneumatic blower was used to apply the compost and seed *(3).* The seed was applied at the same time as the compost, but through a separate line that allowed for mixing with the compost prior to ground placement. The results indicated that the seeded plots showed good vegetation establishment within three weeks of the application. It appears that the most popular method of composting on steep slopes is using a pneumatic blower. Methods for seeding in conjunction with the blower application range from 1) mixing the seed into the machine and blowing the mix onto the ground, 2) blowing a compost-only layer over the ground and then seeding over the top of the compost, to 3) blowing the mix of seed and compost onto the ground and then covering it with a thin layer of "compost-only" to hide the seed from birds *(5)*. When considering placement of the seed mix, it is important to consider the depth of the compost application. A deep layer of compost can hinder the establishment of some plants if the seeds are buried too deep *(3)*.

Recommendations and comments in the reviewed literature concerning the timing of seeding ranged from suggesting that seeding is not necessary on some projects because vegetation will establish on its own, to highly recommending that the composted area be seeded as soon as possible. Furthermore, some compost users recommend that when using a compost product that is coarse and/or woody in nature, that the compost should be field stabilized (aged) prior to seeding or seeded with a special seed mix *(3, 5)*.

Compost filter berms are often used for erosion control and are generally located at the toe or foot of a slope. These filter berms can be seeded or planted at the time of application for permanent vegetation establishment. Another alternative is to wait until the end of the project when the berm can be spread out and seeded. Either way, compost berms can be left at the site and vegetated *(1)*.

In summary, all reviewed articles, reports, and publications that reported a relationship between compost use and vegetation indicated that the use of compost has a positive effect on vegetation establishment and growth. This is due, in general, to decreased erosion and improved soil conditions, which in turn improves growing conditions for vegetation. Research has also shown that compost can help in controlling the establishment of unwanted weedy species.

3.1.1.3 Erosion Control

Erosion occurs naturally, however accelerated erosion can cause many problems relating to decreased vegetation establishment, sediment loading and transport of pollutants to surface waters, and loss of topsoil *(1)*. The use of composted material and mulch is a recognized technique for reducing or eliminating erosion on construction sites *(11)*. In 1993, W & H Pacific *(12)* conducted a demonstration project to evaluate different types of compost for erosion protection. Composted materials were tested on slopes as steep as 2.5H:1V. Results from the demonstration showed that erosion control using the composted materials was equivalent to the hydro-mulch application, which was considered by many (in 1993) to be the most effective method of erosion control. A 1997 publication distributed by the USEPA *(5),* states that on steep embankments along roads and highways, compost can be more effective than traditional hydro-mulch at reducing erosion. In addition, there have been studies conducted by Texas, California, Ohio, and other states that have shown that compost can out-perform hydro-mulch and other standard erosion reduction methods *(13).*

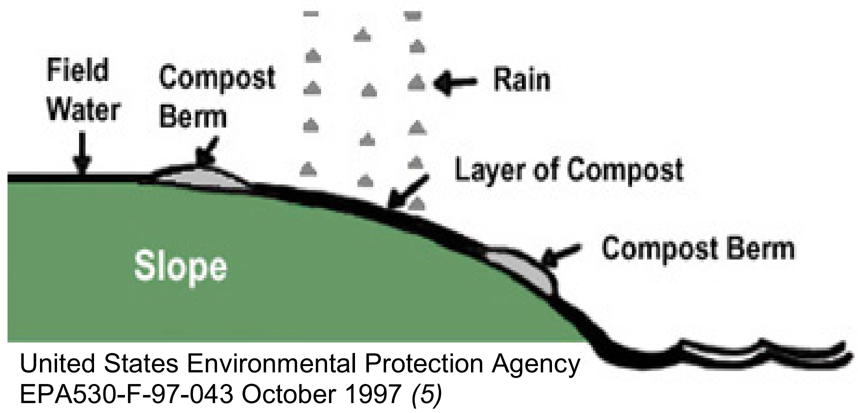
Erosion control using compost works well because the compost layer absorbs the energy of the rainfall (which causes the movement of soil particles), reduces the flow velocity (which improves percolation rates) *(8),* increases water infiltration into the soil surface, increases plant growth cover, increases the water holding capacity of the soil, and decreases soil compaction by increasing soil structure *(1).* A publication from the University of Florida *(7)* points out that compost used as a mulch (blanket) protects soil from the direct impact of rain and wind. This can be very helpful in protecting steep slopes from erosion while vegetation such as shrubs and groundcover are becoming established.

A large-scale study conducted by The Connecticut Department of Transportation (ConnDOT) and the University of Connecticut *(10)* performed a field test to evaluate the use of compost for erosion control on highway slopes with a steepness of 2H:1V. Eight test cells were prepared using different surface treatments. Compost and wood mulch products were used as erosion control filter berm material and erosion control blanket (mulch) – with and without seeding. The surface runoff was collected in buckets at the base of the slope after several storm events over a one-year period. Results indicate that compost and wood mulch application reduced soil loss by 86% compared to bare soils. Sediments reaching nearby surface waters were reduced by 99% when compared to silt fences, and 38% when compared to hydro-seeding applications. The report also stated that if compost is incorporated with the soil, water infiltration into the soil can increase up to 125%.

Demars and Long *(10)* also showed that use of a 7.6 cm (3 in) compost application rate reduced erosion by more than an order of magnitude compared to an untreated slope. Furthermore, limited test results from the same study indicate that a thinner application may achieve a high level of erosion protection and be more economically competitive with the other available methods such as hay and seed.
Many researchers have reported that additional erosion protection can be achieved by using compost filter berms, Figure 1.0. Compost filter berms are contoured runoff and erosion filtration methods usually used for steeper slopes with high erosive potential. Compost berms allow runoff water to penetrate and flow through while filtering sediment and pollutants from the water. Compost berms decrease flow velocity, allowing soil particles to settle out. Berms will work in many of the same areas as blankets but are especially recommended if the slope exceeds 4:1. A compost berm can be planted and

seeded when constructed or the berm can be spread out and seeded when the project is completed *(1)*.

Figure 1.0. Schematic of compost berms and compost blanket on slope.



The US Composting Council *(3)* recommends that to prevent rill formation, a compost berm should be applied approximately 1 m (3 ft) deep over the crest of the slope or mesh with the existing vegetation. Placing a compost filter berm at the base of the slope is also recommended. The USEPA *(5)* suggests that to slow the velocity of water from steep slopes and provide protection for receiving waters, filter berms (mounds) of compost should be installed at the top and/or bottom of the slopes. Tyler et. al. *(13)* pointed out that by having a filter berm at the top of the slope and keeping the compost layer continuous over the 'shoulder' of the slope, the water will hit the slope and ride all the way to the bottom of the slope on the top of the blanket of organic materials. This is because placing the berm at the top of the slope will help keep water from getting under the layer of compost. Many times, if water is allowed under the layer of compost on a steep slope, erosion will occur and the compost may float down the hill on the water.

A University of Connecticut and Connecticut Department of Transportation study *(10)* showed that erosion control filter berms installed on 2H:1V slopes were very effective at retaining eroded solids from runoff while allowing the water to pass through to a water course. In this study, only a minimal amount of soil material was found to have penetrated the berm beyond the first 2.5 cm or 5 cm (1 or 2 in). Researchers reported that the erosion control filter berm used in this study was completely successful. In summary, numerous studies have been conducted that focus on using compost for erosion control on steep slopes. The overwhelming conclusion is that compost is successful at decreasing erosion under the majority of circumstances. The use of compost filter berms at the top and/or bottom of slopes in conjunction with compost blankets has proven to be very effective at erosion control and decreasing sediment loss from slopes.

3.1.1.4 Application Rates

The depth of compost application on disturbed sites is the subject of several studies. Compost should be applied at higher rates than most other soil amendments *(7)*. One of the primary purposes of a compost blanket is to protect the soil surface until vegetation is established *(1)*. Therefore, it is important to ensure that compost is applied in a manner that will encourage plant growth and decrease erosion from the slope. The following recommendations are from the literature reviewed for this report and were found in the conclusion sections of these literature sources (Table 2.0). These recommended application rates are not from construction specifications.

Table 2.0. Compost application rates advocated by various authors

Reference	**Recommended Application Rate**
US Composting Council *(3)*	7.6 cm - 10.1 cm
US EPA *(5)*	5.1 cm - 7.6 cm
Maine Dept. of Environ. Protection *(14)*	slopes 3H:1V or less; 5.1 cm plus addition 1.3 cm per 6.1 m of slope up to 30.5 m slopes between 3H:1V and 2H:1V; 10.1 cm plus addition 1.3 m per 6.1 m up to 30.5 m
University of Florida *(6)*	5.1 cm - 7.6 cm - coarse mulch
University of Georgia *(1)*	2.5 cm - 7.6 cm - mix of fine and coarse grades
Virginia Dept of Transportation *(13)*	5.1 cm

In general, the deeper the compost layer, the greater the erosion control. However, some studies have shown that thinner layers of compost also have a high degree of erosion protection and plant establishment. Researchers at Iowa State University *(9)* used compost blankets of differing depths in their erosion control research. Application rates of 5 cm (2 in) and 10 cm (4 in) were used during the research project. Results showed that in general, the 5 cm blanket applications performed as well as the 10 cm depths. The 10 cm application produced slightly less runoff, however, most of the erosion, water quality, and vegetation benefits were obtained with the 5 cm treatments. The authors pointed out that the ability of the composts to provide these benefits with only 5cm of materials also provides a potential transportation cost advantage over the 15 cm (6 in) topsoil treatments often used in Iowa.

In addition, a University of Connecticut and Connecticut Department of Transportation study *(10)* conducted in 1997 - 1998 used an application rate of 7.6 cm (3 in). This rate was applied to test cells located on a 2H:1V slope. ConnDOT reported that the 7.6 cm application was successful in reducing erosion and the vegetation establishment surpassed the requirements of the ConnDOT. However, ConnDOT also reported that some qualitative test results were obtained for the performance of thinner (3.8 cm and 1.9 cm) applications of compost as erosion control mulch. These results show that thinner applications of compost also achieve a high level of erosion protection. In another study coordinated with the Virginia Department of Transportation to determine the effectiveness of compost, four compost materials were used in two different application rates (5.1 cm and 10.1 cm depths). The final determination for the four materials used on the slopes was that the 5.1 cm application rates provided enough protection for the slopes to reduce erosion to acceptable levels. The report notes that the 10.1 cm application may offer somewhat better protection, but there is concern that the costs for these materials and their application outweighed the slight difference in benefits *(13)*.

The review of the available literature suggests that the deeper (thicker) the layer of compost, especially on steep slopes, the more the slope is protected from erosion. However, it was also noted that the benefits of compost can be realized using layers as thin as 1.9 cm *(10)*. Additionally, vegetation establishment and erosion was not significantly different between the 5 cm (2 in) and 10 cm (4 in) application rates in a recent university study *(9)*.

3.1.1.5 Equipment

The following section contains general comments and suggestions pertaining to methods of slope preparation, compost addition, and seed mix application. No articles were identified that described methods for incorporating compost into the underlying soil layer on slopes that were 2H:1V or steeper. Many of articles and reports reviewed concur that the most efficient and effective method for applying compost to slopes 3H:1V or steeper is to use a pneumatic blower *(13) (2) (1)*.

The US Composting Council *(2)* suggests that prior to applying compost for erosion control, the slope should be horizontally tracked (compacted) with a bulldozer, not smoothed. The council recommends applying the compost using a slinger or blower-type unit, bulldozer, grading blade, or backhoe. The compost layer should be horizontally tracked, especially on heavier soils, to prevent water from moving between the soil-compost interface. When compost is being applied to sites that are difficult to access, blower-type units can be used to propel the compost up to 61 m (200 ft). Researchers at the University of Georgia *(1)* indicate that compost blankets and mats are easiest to apply using a pneumatic blower, especially on slopes where spreaders may not be an option. Finer compost is easier to apply and spreads more evenly using a pneumatic blower. At least 91.4 m (300 ft) of hose is recommended when applying compost with this technology. The authors point out that compost and manure spreaders are effective application devices but only work well on open, gradual slopes. It is best to apply the compost layer on the slope contour or up and down the slope to prevent water from sheeting between the compost and soil surface. Always apply compost at least 0.9

m (3 ft) over the shoulder of the slope or into existing vegetation where possible to prevent rill formation and transport of the compost.

On slopes 3H:1V or steeper or if access is limited the most commonly recommended method of compost application is the pneumatic blower. The long hose allows the compost to be efficiently and evenly applied in most circumstances. Another benefit is that compost can be applied just after rough grading, eliminating the fine-grading step *(13)*. Furthermore, the seed mix can be added right into the compost mix and applied all at once *(2)*.

3.1.1.6 Parent Material/Soil Type

Common excavating practices on highway projects often leaves exposed parent material as the final grade surface. Erosion control and landscaping plantings must then be established in this material. The exposed geological parent material is usually a sub-optimal planting medium because it is low in organic matter and often has plant nutrient imbalances *(15)*.

Compost has been used extensively in revegetation and reclamation of marginal and low quality soils. Benefits include improved soil quality, reduced erosion, enhanced plant establishment, immobilization of toxic metals, and supplying of microbes *(8)*. Studies conducted by the California Department of Transportation (Caltrans) and the University of California, Davis (*16*) revealed that compost is an excellent amendment material for roadside erosion control. One project involved a long series of southwest facing road cuts totaling 3.6 ha; the cuts display 2H:1V slopes. The parent materials are volcanic mudflows cut to 5 – 8 m below the previous soil surface. It was reported in 1999 that the compost amendments were stable through the winter of 1998-1999 with only small areas of slippage. Plant cover for these areas averaged 21%. Another Caltrans study was conducted at the location of a large spoil pile where mixed granitic and metasedimentary rocks from a landslide removal were stockpiled. The area was compacted due to the fine nature of the granitic parent materials from the landslide. Compost was applied to the entire area at a rate of 100 cu m/ha. Next fiber, plant seed, and fertilizer were applied which were followed by straw and a tackifier treatment. Vegetation establishment at the site was slow but a mixture of planted and weedy species gradually developed on this inhospitable site.

In addition to the Caltrans studies, research performed by Penn State University *(2)* involved applying compost to a gravelly site that exhibited a low pH and low organic matter content and was further contaminated with zinc. Researchers at Penn State reported that within 15 months of the compost application, the hillside was covered by a combination of orchard grass, tall fescue and crown vetch.

No research investigations were identified that specifically evaluated the effect of rock content on compost addition and vegetation response.

Highway projects often create the challenge of controlling erosion and establishing vegetation on slopes that are made up of less than optimal plant growth medium. The results of several studies have indicated that compost can improve the plant growth medium and decrease erosion to a degree that allows the establishment of beneficial plants.

3.1.2 Core Case Studies

Case Study #1 California Department of Transportation

The following is a summary of a report titled: The Use of Compost and Co-Compost as a Primary Erosion Control Material (15).

The California Department of Transportation (Caltrans) and California Integrated Waste Management in cooperation with the University of California, Davis has developed multiple full size, experimental slopes for testing erosion control utilizing compost. The first of a series of experiments took place along State Highway 267 in Placer County during the fall of 1998. This project consists of south facing, 2H:1V, slopes that total 3.6 ha (9 ac). Four different types of compost were each tested on three different slopes. The parent material consisted of volcanic mudflow that was cut 5 to 8 m (16.4 to 26.2 ft) below the previous soil surface.

This project was designed to provide the Caltrans staff with the information to create specifications for compost used as a revegetation amendment in the state of California. The Placer County project also evaluated the effectiveness of compost as a method of erosion control.

The compost was applied on the 2H:1V slope using a Challenger rubber tracked tractor. This unit towed a manure spreader applying the compost at a rate of 600 kg/ha (535 lb/ac). The incorporation method consisted of using a 61 cm (24 in) disc, with incorporation around 13 cm (5 in). The soil was seeded using a California native grass mix. This seed mix was drill seeded using a Truax seeder at an application rate between 24.7 - 25.8 kg/ha pure live seed (pls) (22 - 23 lb/ac).

This study confirmed that the use of municipal yard waste compost is a favorable amendment to regenerate soil organic matter that was previously lost due to construction disturbance. Researchers reported that composts were able to regenerate the N availability characteristics of low-nutrient substrates that have been stripped of topsoil organic matter. Compost application provides longer N release duration compared to chemical fertilizer and also provides organic materials for improved infiltration and microbial activity. Although the vegetation community was slow to establish, a mixture of planted species and weeds gradually developed. Plant cover for 2001 and 2002 averaged 21%. In addition, the authors pointed out that in the area where the compost had been stockpiled, a dense stand of planted species developed. This area reportedly had fewer weeds and more perennial grasses than the surrounding area.

Case Study #2: Texas Transportation Institute

The following is a summary of a report titled: The Use of Compost and Shredded Wood on Rights-Of-Way for Erosion Control (17).

In May 1995 the Texas Commission of Environmental Quality, Texas Department of Transportation (TxDOT) and the Texas Transportation Institute (TTI) developed a project evaluating compost as an amendment to control steep slope erosion. The objectives of this project were to determine field performance of compost as an erosion control material for use on highway rights of way. The TTI conducted this study at the TxDOT/TTI Hydraulics and Erosion Control Lab (HECL) west of Bryan, Texas. The layout of this project consisted of three sandy loam and three clay east facing plots on a 3 H:1V. The plots were categorized according to type of amendment that was applied. For each parent material the amendments include one plot each for compost, wood chips with TERRA TAC tacifier, and wood chips with RMB tacifier. Plot dimensions were 6.2 meters (20.3 ft) across and 21 meters (68.9 ft) down slope. The soil erodibility factors for all the sandy loam and clay soil plots were, 0.16 and 0.28 respectfully.

Each plot had a 7.6 cm (3 in) blanket of compost applied, without any incorporation into the soil. The applied compost was a mix of yard debris and biosolids (municipal sewage sludge). Additional tackifiers, TERRA TACK and RMB, were applied at a rate of 6.72 kg/ha (6 lb/ac). The seed mixture was selected from TxDOT's standard seeding specifications includes the following species and rates for clay soils:

- Green Sprangletop 0.67 kg/ha (0.598 lb/ac) pure live seed (pls),
- Bermudagrass 0.90 kg/ha (0.803 lb/ac) pls,
- Little Bluestem 1.23 kg/ha (1.1 lb/ac) pls,
- Indiangrass (Lometa) 1.68 kg/ha (1.5 lb/ac) pls,
- K-R Bluestem 0.78 kg/ha (0.696 lb/ac) pls, and
- Switchgrass (Alamo) 1.35 kg/ha (1.2 lb/ac) pls.

The seed mixture for the sandy loam soils consist of the following species and application rates:

- Green Sprangletop 1.23 kg/ha (1.1 lb/ac) pls,
- Bermudagrass 1.68 kg/ha (1.5 lb/ac) pls, and
- Bahiagrass (Pensacola) 16.55 kg/ha (14.8 lb/ac) pls.

After the seeding was completed each plot was subdivided into 0.5 m^2 (5.38 ft^2) sections. An 8mm camera was positioned perpendicular to each section and used to record 30 samples from all six plots. These samples were then converted into digital images using TIPS and VeCAP software. This software also extrapolated the data and calculated the percent vegetative cover for each sample.

Sediment loss and vegetation results from this case study exceeded the minimum performance criteria set forth prior to the initiation of the project. Compared to the control plots, the sandy loam plots had 85% and the clay plots had 75% less sediment loss through runoff. The compost plots produced 92% vegetation cover on the sand slopes and 99% on the clay slopes (Figure 2.0). However, the compost material apparently contained weed seed, Palmer amaranth (*Amaranthus palmeris*), which contributed much of the vegetative cover. Compost quality control issues were implicated as the source of weed seed. For this reason the desired seed mix did not compete well with the undesirable weed seed. Researchers pointed out that germination of the desired seed mix may also have been retarded by placing the compost over the seed using the same installation as many erosion control blankets. In an attempt to ensure the germination of the desired vegetation, the researchers suggested investigating whether the seed mixture should be placed on top of, or blended in, with the compost. Overall, the researchers reported that the results of this study were most encouraging.

Figure 2.0. Vegetative cover 9 weeks post installation 3H:1V sand slopes, control plot, left; compost plot, center; wood chips with tacifier, right. (photograph from TTI Report 1352-2F) *(17)*

Case Study #3 Iowa Department of Transportation

The following is a summary of a report titled: Impacts of Compost Blankets on Erosion Control, Revegetation, and Water Quality at Highway Construction Sites in Iowa (9).

In April 2000, the Iowa Department of Transportation, Iowa Department of Natural Resources and the Department of Agriculture and Biosciences Engineering at Iowa State University developed a project that would compare quality and quantity of roadside vegetation grown on slopes amended with compost. The scope of this project also evaluated runoff quantity and soil erosion during controlled precipitation events. Utilizing an 8 m (26 ft) long single sweep Norton rainfall simulator investigations ensured that the following rainfall variables were constant: intensity, uniformity of application and raindrop size. All the slopes were south facing at 3H:1V near Ames, Iowa. A total of 96 experimental plots were constructed (6 replications of 16 independent factors) to evaluate 3 compost types, 2 compost depths and rill/interrill development. The findings were compared to a "natural soil" and a topsoil blanket of 15 cm (6 in). Dimensions of the erosion monitoring sections were 1.2 m by 1.2 m (4 ft by 4 ft) for the interrill erosion and 0.9 m by 7.9 m (3 ft by 26 ft) for the rill erosion analysis. All test areas were cultipacked twice, and vegetated plots were fertilized with 500 kg/ha (446 lb/ac) of 13-13-13.

This project tested three different types of compost at an application rate of 5 cm and 10 cm (2 in and 4 in), without any incorporation into the soil. The three composts used were sewage biosolids, yard waste, and bio industrial products (paper mill and grain processing sludge). The seed mixture was selected from the Iowa Department of Transportation specifications includes the following species and rates:

- Oats 108 kg/ha (96 lb/ac),
- Annual rye grass 36 kg/ha (35 lb/ac),
- Red clover 6 kg/ha (5 lb/ac), and
- Timothy 6 kg/ha (5 lb/ac).

Researchers reported that the vegetated interrill plots produced runoff rates that were 64 - 94% less than the control and topsoil plots. The results of a simulated precipitation event indicated that the duration of rainfall required to produce runoff was 4 -12 times longer for composted plots compared to control and topsoil plots. In addition, following a 30-minute precipitation event, the total runoff volume from the composted plots was 98% less than from the control and topsoil plots. Erosion on the interrill plots was from 70 - 99% less than the control and topsoil plots. Rill erosion was 66% less on the compost plots than the topsoil treatment plot. The project also demonstrated that erosion control was immediate on composted plots, even prior to vegetation establishment. As for the three types of compost, yard waste compost typically produced significantly less runoff, erosion, and exported pollutants than the other two composts.

The authors pointed out that the erosion and runoff reductions from the 5 cm and 10 cm application depths were not significantly different. Furthermore, it was reported that the depth of the compost application was not an issue in achieving significant cover crop growth of the seed mix. As an additional benefit, throughout all six plots there was at least 42% less weed emergence on the composted plots than the control plot and topsoil plot.

In summary, this study reported that, in general, erosion was significantly reduced on the composted plots compared to the control and topsoil treatment plots. Planted cover crop growth was statistically equivalent among all of the treatments; however, the composted plots had significantly less weed growth than the control or topsoil treatment plots.

Case Study #4 Idaho Transportation Department

The following is a summary of a report titled: Erosion Control and Revegetation Demonstration Project Report, Horseshoe Bend Hill, Idaho State Highway 55 (18).

Idaho Transportation Department organized a project that evaluated the feasibility and economics of using products, technologies, and methods that have demonstrated propensities toward helping in the rapid and successful establishment of desired vegetation on disturbed sites. The scope of this demonstration evaluated commercially available products to assess their effectiveness in helping stop erosion by reestablishing vegetation at the subject site. Different seed mixes were also used to evaluate which species would perform best under adverse growing conditions. This project began in January 1997 and took place at Horseshoe bend hill along Idaho State Highway 55. The layout of this study consisted of six sites with slopes at 1H:1V or steeper. The parent material for each cut slope is decomposed granite strewn with rocks and small boulders.

Sites 71, 72, 73, and 74 were hydro-seeded in a one step process using 18.9 L / 2 ha (5 gal/ac) Kiwi Power, 2240 kg/ha (2000 lb/ac) fertile fiber and 112 kg/ha (100 lb/ac) cliffhanger tack. Kiwi Power is an organic soil amendment that provides necessary soil enzymes. Fertile fiber is a composted poultry based mulch. Cliffhanger tack was used as a tacifier to help anchor these products and the seed. Site 75 used composted yard waste and wood shavings that was blown onto the surface at a rate of 33.5 yd^3/ac. Site 76 used a bovine based manure compost that was also blown onto the surface at a rate of 33.5 yd^3/ac. Due to the nature of each slope, incorporation of the above amendments was not an option. Below (Table 3.0) is a list of six different revegetation seed mixes that were applied to the sites:

Table 3.0. Seed mixes Case Study # 4

Site 71

Species	**% Mix**
Ephraim crested wheatgrass	24.03
Thickspike wheatgrass	20.81
Canby bluegrass	5.01
Steptoe barley	21.03
Yarrow	5.26
Lewis bluefax	5.31
Small burnet	9.02
Rubber Rabbitbrush	0.60
Louisiana sage	0.93
Total	**40 lb pls**

Site 72

Species	**% Mix**
Steptoe barley	19.97
Ephraim wheatgrass	17.12
Canby bluegrass	5.01
Covar sheep fescue	5.57
Lewis bluefax	5.05
Yarrow	4.99
Indian blanketflower	13.28
Small burnet	8.03
Sainfoin	15.56
Sherman bluegrass	6.05
Louisiana sage	0.88
Rubber Rabbitbrush	0.57
Total	**20.87 lb pls**

Site 73

Species	**% Mix**
Steptoe barley	16.87
Covar sheep fescue	11.37
Sherman bluegrass	6.60
Sand dropseed	12.98
Bottlebrush squirreltail	2.71
Prostate bitterbrush	7.61
Lewis bluefax	4.86
Yarrow	4.81
Indian blanketflower	6.42
Small burnet	10.18
Sainfoin	1.15
Rubber Rabbitbrush	4.59
Louisiana sage	1.15
Total	**21.81 lb pls**

Site 74

Species	**% Mix**
Magnar wildrye	14.39
Covar sheep fescue	10.38
Bottlebrush squirreltail	6.97
Sand dropseed	12.06
Secar bluebunch wheatgrass	15.57
Small burnet	9.92
Sainfoin	8.86
Lewis bluefax	4.70
Yarrow	4.65
Louisiana sage	0.85
Rubber Rabbitbrush	0.53
Total	**40 lb pls**

Site 75

Species	**lbs/ac**
Ephraim wheat grass	2.5
Sand dropseed	2.5
Lewis bluefax	3
Palmer penstemon	1
Farewell to spring	1
Total	**12 lb pls**

Site 76

Species	**lbs/ac**
Siberian wheatgrass	2.5
Sand dropseed	2.5
Lewis bluefax	3
Palmer penstemon	1
Farewell to spring	1
Total	**12 lb pls.**

The vegetation performance for this study was evaluated by analyzing the plant density. The density was determined by 0.093 m^2 (1 ft^2) randomly placed quadrats. The sites that were seeded with cereal grain had an overall denser cover. Sites that used Kiwi Power (71-74) resulted with the highest amount of plant density ranging from 20-30 plants per square foot. It was noted that site 76 had the greatest concentration of weeds. This could have been a result of dietary habits of cattle and their inability to digest weed seed. The plant species that performed exceptionally include: Steptoe barley, Yarrow, Rubber rabbitbrush, Sainfoin, Intermediate wheatgrass, Ephraim wheatgrass, Bluebunch wheatgrass, Canby bluegrass and Farewell to spring. Researchers suggested that it is advantageous to use early seral stage species, because they are soil builders designed to adapt and succeed in poor conditions. These early seral stage plants build soils, both physically and biologically so that higher seral stage species can grow on the site at a later date.

In conclusion, this project demonstrated that compost is a viable option when revegetating steep slopes with highly erosive soils. Kiwi products did exceptionally well as an amendment for erosion control through plant establishment. This study concluded that poultry based compost is five times more effective than cattle based on a cost per effective pound basis. According to Kathy Ford , with the Idaho Department of Transportation, vegetation density continues to improve at this site and the Department of Transportation views the study as a success *(19)*.

Case Study #5 Connecticut Department of Environmental Protection
The following is a summary of a report titled: Field Evaluation of Source-Separated Compost and CONEG Model Procurement Specifications for Connecticut Department of Transportation Projects (10).

The research for this project was sponsored by the Joint Highway Research Advisory Council of the University of Connecticut and the Connecticut Department of Transportation (ConnDOT) in cooperation with the Connecticut Department of Environmental Protection. The objective of this study was to evaluate compost used as an erosion control mulch on highway slopes. The function of the compost mulch application was to prevent erosion by dissipating the erosive energy of raindrops and help keep runoff water in sheet flow to protect the soil surface and promote the establishment of vegetation. In addition to the erosion control mulch, erosion control filter berms were placed at the site to evaluate sediment filtering during runoff events. The function of the compost berms was to act as a porous dam allowing runoff water to drain while filtering sediment. The layout of this study consists of seven experimental cells and one control cell (Figure 3.0). Each cell was 3 m by 10.7 m (10 ft by 35 ft), on a slope of 2H:1V. The field site for this project was located between routes 198 and 6 in Chaplin, CT. This study evaluated the erosion performance of compost for eight precipitation events over a one-year period from fall 1996 to summer 1997.

Figure 3.0. Experimental test plots from Case Study #5. (photograph courtesy of Kathy Alexander ConnDOT)

The three compost sources used in this study were Manchester compost, Glastonbury mulch and Earthgro compost. The Manchester compost was derived from yard trimming compost from leaves and grass that was screened. The Glastonbury mulch was from chipped and shredded wood that was screened between 5.1 cm - 7.6 cm (2 in -3 in). Earthgro compost consisted of yard trimmings compost from leaves, grass, and shredded brush and was also screened. The application rate for all three composts was 7.6 cm (3 in) thick without any incorporation into the soil. Native grass seed was applied to the Manchester and Earthgro composted plots in accordance with Connecticut Department of Transportation specifications. Vegetation performance was determined by counting species on randomly placed square foot quadrats.

All three plots exceeded the minimum grass germination ConnDOT requirement which is 100 plants per square foot. The results are from random locations within each cell after 10 months of growth are prepared in Table 4.0.

Table 4.0. Results of plant density within cells 3 and 8

(Cell Number) Compost Amendment	Plant Count per square foot
(3) Manchester Compost	290
	360
	306
(8) Earthgro Compost	180
	490
	270.

Results from the study show that for compost used as an erosion control mulch (with or without seeding), a 7.6 cm (3 in) application reduces erosion by more than an order of magnitude compared to an untreated slope. For an 18 mm (.70 in) 2-hour precipitation event the control had 4.3 g/l of runoff compared to 0.6 g/l runoff rate for the cell amended with Manchester compost. Limited test results for the performance of 1.9 cm - 3.8 cm (0.75 - 1.5 in) applications of compost show that thin applications may achieve a high level of erosion protection and be more economically competitive with the other available methods such as hay and seed. Furthermore, there was no significant release of nutrients or soluble salts from the test plots. Conductivity of the runoff from the control plot was less than .05 mmhos and the treated cells produced slightly less conductivity than the control.

Researchers also reported that the erosion control filter berm was very effective at retaining eroded solids from runoff while allowing the water to pass through to a watercourse. Maintenance of the berm was minimal and this application may be a cost-effective alternative to the geosynthetic silt fence.

3.1.3 Standard Specification for Compost for Erosion/Sediment Control

Each state has unique requirements that determine how its roadsides are developed and maintained *(3)*. When compost is used as an amendment the chemical, biological, and physical properties of compost may vary depending on the location of origin. Each state has its own specification criteria to guarantee the compost will meet environmental standards. This is to ensure that the product will perform reliably and that it is competitive with other erosion control alternatives. The American Association of State Highway and Transportation Officials (AASHTO) specification for compost quality is a brief summary of the current parameters and minimum requirements of using compost blankets (Appendix B).

3.2 Equipment Evaluation

Individual pieces of equipment were evaluated that have the potential to safely and efficiently apply and incorporate compost on steep slopes. Some of the equipment identified is routinely used on steep slopes while others have the potential to be applied to steep slope applications. No single piece of equipment is ideally suited to all circumstances, rather the physical conditions of individual sites will impart an influence on equipment selection. The following narrative identifies the commercially available equipment candidates and their respective advantages and disadvantages.

3.2.1 Compost Incorporation Equipment

There are a number of potential equipment options available for incorporating compost into substrates on 2H:1V (50 percent) slopes. However, only a handful have actually been used for this or for similar work. As with most construction projects, it is unlikely that any one given piece of equipment will be the optimum choice in all circumstances, but rather that some will perform better than others for each specific set of job site conditions. Potential compost incorporation tool carrier equipment generally falls into six categories:

1. Heavy tracked construction equipment, including most crawler type dozers, loaders, and tracked log skidders,
2. snow cat based utility vehicles,
3. wheeled type tool carriers, including log skidders and specialized tractors,
4. selected agricultural equipment,
5. miscellaneous equipment such as specialized excavator attachments, and
6. gravel spreaders on back of dozers.

The first three categories have been used on 2H:1V (50 percent) slopes, most commonly in mine reclamation, logging, ski area maintenance, and European steep slope agriculture. Each of five equipment categories is discussed in the following sections.

3.2.1.1 Safety

Any type of tillage operation on 2H:1V (50 percent) or steeper slopes will have inherent safety concerns with the relatively high potential of roll-over or run-away. The roll-over potential of equipment is rarely given in company literature or specifications due to liability concerns and is therefore unknown for many machines including most crawlers, skidders, and tractors. General construction practice and contractor experience will guide equipment selection in many cases. Many models of equipment listed utilize hydrostatic transmissions of various types. Nearly all of these will have dynamic braking and continuous power to all tracks or axles. These machines will generally be much more controllable on steep slopes as opposed to geared/clutch type machines. The roll-over problem would be avoided when using an excavator mounted tillage implement, but the slope distance that can be worked with these machines will be limited to the maximum boom reach. The contractor's choice of equipment will have to consider safety as the primary parameter for the specific equipment selected.

3.2.1.2 Equipment Category 1: Heavy Tracked Construction Equipment

Crawler dozers are available in a wide variety of sizes and track configurations for both purchase and rental through common construction equipment dealers and rental shops. Both new and used machines are widely available from most heavy equipment manufacturers including Caterpillar (http://cmms.cat.com), Komatsu (http://www.komatsuamerica.com), and John Deere (http://www.deere.com). Implement attachment has usually been via custom mounting on the ripper attachment; counter balancing may be required. Extended track frames, such as the Caterpillar D6R XR, or extra track width gage such as the D6R XW, and the numerous low ground pressure (LGP) models from both John Deere and Caterpillar would likely be advantageous on steep slopes for both extra stability and traction. The two Caterpillar tracked skidders (Models 517 and 527) are similar to crawler dozers, but exhibit very long rear extended tracks and would likely be very applicable to this work. Compost incorporation utilizing these machines may be achieved by either/or a front mounted brush type blade (Figures 4.0 and 5.0) with at least 15 cm (6 in) teeth and a rear mounted chisel plow, disk, or ripper, if multiple close space shanks are available.

Advantages of this type of equipment are:

- widely available for purchase or rental,
- large variety of sizes and track configurations available,
- numerous factory and aftermarket attachments available,
- contractor familiarity with equipment, and
- machines are expected to be essentially immune from the effects of rocky soil.

Disadvantages include:

- most units are heavy,
- potentially high capital cost,
- implement attachment may require custom fabrication,
- the practical slope limit is 50 percent with operation generally confined to up and down slope only,
- may require a less steep slope or bench for turning, and foremost,
- all will likely be relatively slow for this type of work, requiring a greater time allotment and increased expense over other potential options.

Numerous manufacturers produce brush rakes for attachment to nearly all skidder and crawler models used in the logging industry (Figure 6.0). A few of these are Shamrock Steel Fabrication (http://www.shamrocksteelfab.com), KENCO (http://www.kencoattachments.com), Craig Manufacturing Ltd (http://www.craig-mfg.com), Hunt Tractor, Inc. (http://www.hunttractor.com), and NW Attachments (http://www.goshenequipment.com).

Figure 4.0. Caterpillar Model 517 tracked skidder. (photograph from http://cmms.cat.com)

Figure 5.0. Caterpillar Model 527 tracked skidder. (http://cmms.cat.com)

Figure 6.0. Craig severe service rake. (http://www.craig-mfg.com)

3.2.1.3 Equipment Category 2: Snow Cat Based Utility Vehicles

The second equipment category, the snow cat based tool carrier or utility vehicles, has a proven track record for working on 2H:1V (50 percent) slopes. As in crawler dozers, snow cats are available in a wide variety of sizes and track configurations from several manufacturers. Nearly all major present manufacturers, including Tucker, PistenBully (Kassbohrer), and Bombardier produce machines (Figures 7.0, 8.0, 9.0 and 10.0) with undercarriages designed specifically for use on "dry" ground and both factory and aftermarket parts are available to convert other machines (Logan Manufacturing Company) from snow based to soil based operation (Figure 11.0 and 12.0). Most are rated to climb a 1H:1V (100 percent) slope and can operate across a 2H:1V (50 percent) slope. Bombardier machines are rated at 1.5H:1V (60 percent) up and down slope, 2.5H:1V (40 percent) across slope. Many of these machines are available with both front and rear hydraulics and some may offer Power Take Off (PTO) options.

Equipment advantages are:

- proven ability to work on 2H:1V (50 percent) slopes under conditions similar to those expected for this work, including the ability to turn on slope,
- capable of relatively fast speeds,
- very maneuverable (some models feature counter rotating tracks for turning in place), and
- a variety of attachment options are available, including some agricultural tractor features, such as 3 point hitches with PTO arrangements.

Disadvantages include:

- limited availability (unlikely rental units would be available for this type of work),
- units generally do not handle large loose surface rock well, and
- maintenance requirements likely higher than some other equipment.

Figure 7.0. PistenBully100 All Season with front mounted mulcher. (photograph from http://www.pistenbully.com)

Figure 8.0. Tucker Sno-Cat Corporation Terra model. (photograph courtesy Tucker Sno-Cat, http://www.sno-cat.com)

Figure 9.0. Bombardier Go-Tract. (photograph from web page http://www.bombardier.com)

Prices for new snow cat based machines range upward from the approximate $100,000 base price for the PistenBully 100 All Season. The Tucker Terra runs between $150,000 to $160,000. Used machines can be found for under $20,000 (Peterson Equipment).

Figure 10.0. Bombardier Muskeg model.

Figure 11.0. Modified LMC 3700C with hydraulically operated broadcast seeder and rear mounted spike harrow at the Zortman Mine in north central Montana. (Arrowhead Reclamation/Troy Smith photograph).

Figure 12.0. Arrowhead Reclamation LMC unit on 50 percent slope. (Troy Smith photographer)

3.2.1.4 Equipment Category 3: Wheeled Type Tool Carriers

Wheeled tool carriers, such as log skidders and specialized tractors, have been used on 2H:1V (50 percent) slopes under a variety of rough ground conditions, and may be a viable alternative for compost incorporation on steep slopes. Some four-wheel drive agricultural tractors may also be suited for this type of work under specific conditions and proper balancing. However, these vehicles are generally unproven in this application.

There are numerous log skidder models available from a number of manufacturers, including Caterpillar, Clark, Franklin Tree Farmer, John Deere, Ranger, Timber Jack. Typically these machines are fitted with a front stacking blade and a rear mounted win or grapple on either fixed or swivel booms. For compost incorporation use, considerable custom modification for rear implement attachment would be necessary on most, if not all, machines. Brush rakes are available for front blade attachment for most models which may be an effective incorporation tool. It is unknown to what extent these machines would be able to operate across and turn on 2H:1V (50 percent) slopes in loose materials.

Specialized tractors include the AEBI Terratrac line, with current models being the 44.5 kW (61 hp) TT70S (Figure 13.0) and the 60.2 kW (82 hp) TT95 (Figure 14.0). The TT70S is being replaced by the TT75 for the 2004 year, with similar specifications that are not yet available. Base prices for the TT75 and TT95 are $54,686 and $64,000 respectively which does not include an enclosed cab, PTO, or 3 point hitches, all of which are extra cost additions. These tractors are manufactured specifically to operate on steep slopes (up to 65 percent "under ideal conditions") under a wide variety of conditions and would not likely incur additional maintenance due to this work. The most common application in the United States is for ski area run maintenance, but they are regularly employed for steep slope agriculture in Europe. A very large variety of attachments, ranging from front end loaders, snow blowers, and plows, to cement mixers, is available. The TT70S offers four wheel steering. Both models offer front and rear 3 point hitches, PTO shafts, and hydraulics. Both models also feature hydrostatic transmissions (mechanical gear drive optional), available dual wheels with high traction tires, and individually selectable locking differentials at both front and rear. Maximum dual range speeds are 12 km/hr (7.5 mph) and 40 km/hr (25 mph). The four wheel steering of the TT70S would allow crab mode steering and the potential to horizontally traverse some slopes that would otherwise not be possible. Given the standard agricultural attributes of these machines, any readily available 3 point mount agricultural implements can be attached and therefore the tilling implement selection could be readily optimized for specific site conditions. <u>If these machines can demonstrate sufficient traction to operate on the 50 percent cut slopes</u>, they may be the most cost effective machines for this work.

The advantages of these machines includes:

- relatively light weight,
- high operating speed,
- high maneuverability and some have the capability of operating across and turning on steep slopes,
- ability to operate on slopes in excess of 50 percent,
- capability to use most 3 point attachment agricultural implements without modification (specialized tractors only), and
- probable low maintenance and down time.

Disadvantages include:

- unknown performance on 50 percent slopes composed of loose materials and/or loose rock,
- unknown width of implement capable of moving up-slope, and
- the probable unavailability for rental (availability for purchase is good).

AEBI Terratrac units are known to exist at several ski areas in this vicinity, including Big Mountain near Whitefish Montana, Bridger Bowl (Figure 15.0) near Bozeman, Montana, and at Schweitzer Mountain near Sandpoint Idaho. It is unknown if any of these are available for rental.

Figure 13.0. AEBI Terratrac model TT70S with four wheel steering. (photograph from AEBI North America, Inc., web site http://aebi-us.com)

Figure 14.0. AEBI Terratrac model TT95. (photograph from AEBI North America, Inc. web site http://aebi-us.com)

Figure 15.0. Bridger Bowl Ski Area's hydrostatic drive AEBI Terratrac TT88. (RRU photograph)

3.2.1.5 Equipment Category 4: Selected Agricultural Equipment

Tracked agricultural tractors may have application for compost incorporation on 2H:1V (50 percent) slopes. At least one reclamation contractor has used a Caterpillar Challenger 65 for work on 2H:1V (50 percent) slopes (J & M Land Restoration, jmland2@aol.com). This contractor used the Challenger for both application and tillage with normal heavy duty agricultural implements. This equipment does require less steep access at both the top and bottom of slope and can work up and down slope only. All agricultural tracked tractors are expected to be readily available for rental or purchase.

Current Challenger models, manufactured by AGCO (http://www.challenger.agcocorp.com) (include four units in each of the MT 700 and MT 800 series with power ratings from 138 kW (185 hp) to 433 kW (500 hp) (Figure 16.0). Maximum track tread widths are 76 and 91 cm respectively for the two series. The MT 700 series is available with a 4:1 creeper transmission. Maximum speed for all eight models is 39.7 km/h (24.6 mph). Track systems for all Challenger models feature a suspension system and it is expected that these machines would be capable of operation over moderate size rock. Previous Challenger models included the 35, 45, 55, 65, 75, 85, and 95 series, with power ratings ranging from 129 kW (175 hp) to over 301 kW (410 hp). All of these models have 3 point hitch options and implement hydraulics, which may be appropriate for this project.

Figure 16.0. AGCO Challenger series MT 800 tractor. (photograph from http://www.challenger.agcocorp.com)

John Deere (http://www.deere.com) builds eight somewhat similar tractors in their 8000T and 9000T series with power ratings from 125 kW (170 hp) to 331 kW (450 hp) (Figure 17.0). These machines may also be suitable for this type of work. Their performance on steep slopes is unknown.

Figure 17.0. John Deer model 9320T. (photograph from http://www.deere.com)

Case-IH lists 3 tracked models, the STX 375, STX 425, and STX 450. All of these models feature a four track design with either 76 cm (30 in) or 91 cm (36 in) tracks available (Figure 18.0). Power ratings for these tractors ranges from 246 kW (330 hp) to 295 kW (395 hp). No information on steep slope performance was found for these tractors.

Figure 18.0. Case IH model STX 450 (photograph from http://www.caseih.com)

Advantages of agricultural tracked tractors include:

- potential operation at higher speeds than obtainable with tracked construction equipment,
- built for operation in soils and hence minimal extra maintenance expected from steep slope tillage operations,
- suspension systems within tracks should accommodate operation over moderate sized rock,
- large selection of track widths are manufactured, and
- units are widely available from agricultural dealers for both rental and purchase, as both new and used machines.

Disadvantages include:

- generally unknown performance characteristics on 50 percent slopes, and
- all will require more gently sloping areas at top and toe of slope for turning.

3.2.1.6 Equipment Category 5: Excavator based equipment

Foremost in this equipment category are specialized excavators and excavator attachments. Lang Tool Company (http://www.langtool.com) markets a modified excavator (290-LTC) with greatly enhanced hydraulic systems for operating specialized attachments (Figure 19.0). Two of these attachments, the rock grinder and the *in-situ* blender, would be capable of mixing compost to well over 4 in in virtually any substrate (Figures 20.1, 20.2 and 21.0).

Figure 19.0. Lang Tool Company 328 kW (440 hp) enhanced hydraulics tool carrier.

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Figure 20.1. Lang Tool Company rock grinder dimensions.

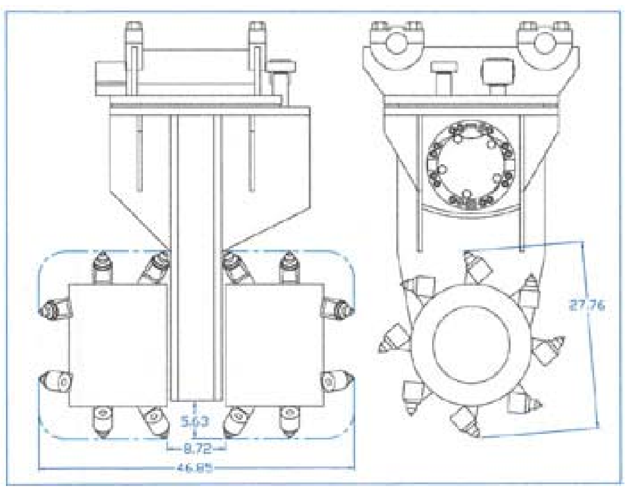

Figure 20.2. Lang Tool Company rock grinder on 290 LTC tool carrier.

Figure 21.0. Lang Tool Company *in-situ* blender.

In-situ mixing attachments have also been manufactured in several widths and diameters by AFFCO (affco@in-tch.com). This company manufactures these attachments to the customer's specifications. Mixing depths far greater than 10 cm (4 in) have been achieved with these units, which attach to standard production excavators (Figure 22.0).

Advantages of excavator based tilling implements are:

- tilling can be accomplished on any steepness of slope,
- tilling depths to in-excess of 1 m (3 ft) available, and
- greater mixing ability than standard tillage implements.

Disadvantages include:

- limited slope length can be tilled from one position,
- limited availability of equipment, and
- relatively slow production as compared to other available methods.

The excavator based tillage may be the best selection where limited space and slope steepness prevent use of other tillage methods.

Figure 22.0. In-situ mixer attachment manufactured in Anaconda, Montana by AFFCO.

Use of excavator based mixing tools will be limited by the boom length of the specific excavator. Maximum excavator boom reach is generally about 8.5 to 9 m (28-30 ft). If both the top and bottom of the slope are accessible, the maximum slope length that can be effectively mixed would be double the boom reach or approximately 17 m (56 ft). Lang Tool Company (info@langtool.com) has units available for rental nation wide.

3.2.2 Compost Application Equipment

Only blower units are being considered for this project. Three manufacturers produce blower units, some of which are available as self-contained units suitable for either truck or trailer mounting. Most of these units were originally designed to deliver wood wastes and blow landscape materials (usually bark). There have been some reported problems working with material that contains rock or if the compost has a high moisture content. Manufacturers of blower units include Express Blower (Rexius) (http://www.expressblower.com), Finn Corporation (http://www.finncorp.com), and Peterson Pacific Corporation (http://www.petersonpacific.com).

Express Blower, formerly Rexius, builds seven models. These are the TM-10, TM-20, EB-30, TM-30, EB-40, EB-60, and EB-90. TM models are self contained while the EB models are integrated truck units. All model suffix numbers represent the capacities of the units in cubic yards (cy). The EB-40, EB-60, and EB-90 models all share the same major drive and feed components and deliver materials at 0.76 to 1.53 m^3 (1 to 2 cy) per minute. The respective capacities of these units is 30.6 m^3 (40 cy), 45.9 m^3 (60 cy), and 68.8 m^3 (90 cy). All of the Express Blower models are capable of delivering materials up to and exceeding 91 m (300 ft). On-board hose lengths range from 85 m (280 ft) to 137 m (450 ft).

Finn units include four models, all of which are self contained and can be mounted on either trucks or trailers. Models are BB-302 (1.1 m^3, 1.5 cy), BB-605 (3.4 m^3, 4.5 cy), BB-908/916 (6.3 m^3, 8.2 cy), and the BB-1240 (28 m^3, 36 cy). All of these models are rated for blowing "wood mulches, compost and other bulk materials" up to 91 m (300 ft).

Peterson Pacific manufactures only one model, the BT 40-A, a 30.6 m^3 (40 cy) unit with up to 61 m^3 (80 cy) per hour delivery through up to 244 m (800 ft) of hose. This is an integrated unit for a Class 8 truck chassis.

The Peterson Pacific BT-40-A, the Finn BB-1240 and the Express Blower models EB-40, EB-60, and EB-90 all appear to be well suited for compost application (Figures 23.0, 24.0 and 25.0). Selection of the specific unit to be used will depend on the actual characteristics, primarily the density and moisture and rock content, of the compost; the other material handling equipment available; and the location of the unit in relationship to the construction site.

Figure 23.0. Express Blower (Rexius) model EB-60.

Figure 24.0. Finn Model BB-1240.

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Figure 25.0. Peterson Pacific BT-40-A bark blower.

3.2.3 Equipment Summary

It is apparent that several options may be available for compost incorporation on steep slopes. However, to date, only a snow cat-based utility vehicle has been successfully demonstrated in actual construction on 2H:1V slopes where access is not available at the top of the slope. These machines are not currently in the mainstream of construction equipment, but are available. The use of wheeled vehicles, especially tractors such as the AEBI, remain a potential method, but their abilities on 2H:1V cut slope needs to be demonstrated before any planned use is made of these machines. Where the acreage of cut slope is limited within a particular project, the use of on-site tracked construction equipment may remain the best alternative. The expected slow production in this circumstance would be offset by the negated need to acquire an additional piece of equipment. If access is available at the top of the slope, tracked agricultural tractors would be a good alternative. However, each model will need to be evaluated for safe use.

The excavator based tilling implements are very robust and could be used with nearly all weakly to moderately indurated geologic materials. The anticipated slow production of these machines will likely limit use of these machines to small difficult areas. A summary of equipment manufacturers and suppliers is presented in Appendix C.

4.0 Site Reconnaissance

Field evaluation of two candidate research sites with three potential test plots occurred during Phase I of the project. A site in northwest Montana near Happy's Inn was visited, as well as a second site south of Colstrip in the southeastern part of the State (Appendix A). The Happy's Inn site revealed several steep, erosive cut slopes resulting from recent road work. A glacial till research site and an alluvial rock research site were identified. South of Colstrip, a candidate research site was identified on erosive shale parent material. The cut slopes to be used for research were not visible since reconstruction of the road has not begun. Inference of the location, length, and erosivity of cut slopes was made possible using survey stakes identifying the new road alignment coupled with parent material characteristics in existing road cuts. Refinement of the Colstrip South research site will be required after construction is initiated.

4.1 Happy's Inn

The Happy's Inn candidate research sites are located approximately 80.5 km (50 miles) west of Kalispell on U.S. Highway 2. During reconstruction of the roadway several years ago, erosive materials were exposed in cut slopes throughout the project. These erosive materials are principally glacial loess and till that is locally very susceptible to erosion. Revegetation of these materials, and alluvial gravel encountered on cut slopes, has resulted in limited vegetation establishment and prevalent erosion. Personnel from MDT identified these cut slopes as candidates for compost addition to enhance vegetation establishment and to mitigate sediment releases occurring from these slopes. Construction of research plots will be performed by a contractor hired by MSU with oversight provided by MDT and MSU.

4.1.1 Glacial Till Candidate Research Site

The glacial till research site is located on a south-facing slope at Milepost 67 on U.S. Highway 2 west of Kalispell. The slope is approximately 30 m (100 ft) in length and a couple hundred meters in width. Gullies 1 m (3 ft) in depth have formed over the past several years. The site is essentially unvegetated and rapidly eroding. Currently the slope steepness is approximately 65%. The soil texture was silt to silty clay with common rock fragments. The soil pH was approximately 6.5. No visual evidence of organic matter in the soil was observed. No visual evidence of salt crusts or excessive salinity were observed. Images of the site are presented in Figures 26.0 and 27.0.

Figure 26.0. Eroded south-facing glacial till candidate research site located near Milepost 67 on U.S. Highway 2.

Figure 27.0. Glacial till candidate slope viewed from the top of the cut.

Construction of a research test plot will require regrading of the slope to an ungullied condition with slope steepness of 2H:1V. Access to the top of the slope by a dozer appears to be possible without significant problems. It may be necessary to relocate or temporarily remove the right-of-way fence. Excess fill material generated by regrading will need to be hauled away from the site. Conceptually, this will be accomplished by MDT Maintenance personnel. Compaction of the soil on-slope was presented as a notable concern during field reconnaissance. It is desirable to have plant roots grow into the subsoil, so it was proposed that ripping of the slope occur after establishment of the final grade. Observation of mud flowing on frozen or compacted soil was made on the north-facing slope at this location. A run-on control ditch will be constructed to ensure that the research plot does not receive additional water inputs from above the slope.

It is hypothesized that addition of organic matter to the top 10 cm (4 in) of the regraded glacial till coupled with ripping of the top 30 - 45 cm will allow for establishment and development of the seeded vegetation. Construction of the test plot is proposed for late summer-early fall 2003 in anticipation of fall 2003 seeding.

4.1.2 Alluvial Rock Candidate Research Site

The alluvial rock research site is located on a south-facing slope immediately adjacent and east of the Elk Creek Road junction with U.S. Highway 2. The slope is approximately 15 m (50 ft) in length and several hundred ft in width. No evidence of notable erosion is present due to the high permeability of the sandy soil and rock. The site is sparsely vegetated with several small fescue plants per square foot. Currently the slope steepness is approximately 50%. The soil texture was sand to loamy sand with common rock fragments. The soil pH was approximately 7.0. No visual evidence of organic matter in the soil was observed. No visual evidence of salt crusts or excessive salinity were observed. Low water holding capacity and low fertility appear to limit the development of vegetation at this site. Images of the site are presented in Figures 28.0 and 29.0.

Figure 28.0. Evaluation of parent material at the alluvial rock candidate research site.

Figure 29.0. Coarse textured glacial outwash characteristic of the alluvial rock candidate research site.

Construction of a research test plot will not require regrading of the slope since it is presently at the desired steepness. Access to the top of the slope appears to be possible without significant problems. It may be necessary to relocate or temporarily remove the right-of-way fence. A run-on control ditch will be constructed if necessary.

It is hypothesized that addition of organic matter to the top 10.1 cm (4 in) of the alluvial rock coupled with chisel plowing or ripping the top 15 - 30 cm (6-12 in) will allow for establishment and development of the seeded vegetation. Construction of the test plot is proposed for late summer-early fall 2003 in anticipation of fall 2003 seeding.

4.2 Colstrip South Project

The Colstrip South road reconstruction project has recently been awarded and commencement of construction is expected imminently. Unlike the Happy's Inn research site, test plots will be constructed synchronously with construction. Therein, description of the specific research slope selected, dimension of plots and limitations to plant growth are only presented conceptually. Refinement of the research site location and approach to implementation will require coordination with the MDT project engineer and contractor's representative.

4.2.1 Tongue River Shale Candidate Research Site

The Tongue River shale research site will be located on a west-facing slope south of Colstrip Montana along the reconstructed section of Montana Highway 37. The research slope is expected to be 15 - 30 m (50 - 100 ft) in length. The erosivity of the shale parent material is expected to be high with silt to clay size particles dominating the soil texture. Rock content is expected to be minimal. The site will be unvegetated and recently graded to approximately 50% or 2H:1V. The soil pH is expected to exceed 7.0, and have essentially no organic matter in the regraded subsoil. Elevated salinity and sodicity are potential concerns that may further retard plant development. Chemical analysis of the soil will be required to evaluate the potential influences of salinity and sodicity. Erosion of the soil and low fertility are expected to limit the development of vegetation at this site. An image of the site is presented in Figure 30.0.

Construction of a research test plot will be accomplished by the construction contractor with oversight provided by MSU and MDT. The research slope will be constructed in accordance with the construction specifications developed by MDT. Compost application to steep slopes will be performed in accordance with the experimental design described in Phase II.

It is hypothesized that addition of organic matter to the top 10 cm (4 in) of the Tongue River Shale coupled with chisel plowing or ripping the top 15 cm - 30 cm (6-12 in) will allow for establishment and development of the seeded vegetation. Construction of the test plot is proposed for late summer-early fall 2003 in anticipation of fall 2003 seeding.

Figure 30.0. The Tongue River shale outcrops in this roadcut along Montana Highway 37 south of Colstrip.

5.0 Results and Discussion

Synthesis of the literature review, equipment evaluation and reconnaissance of field sites in Montana has led to preparation of the Phase II proposal. Phase I of this report emphasized collection of research findings from investigators across the country, therein no re-interpretation of their findings is offered. Implementation of Phase II in Montana will allow for collection of data unique to the revegetation challenges faced by MDT on steep cut slopes.

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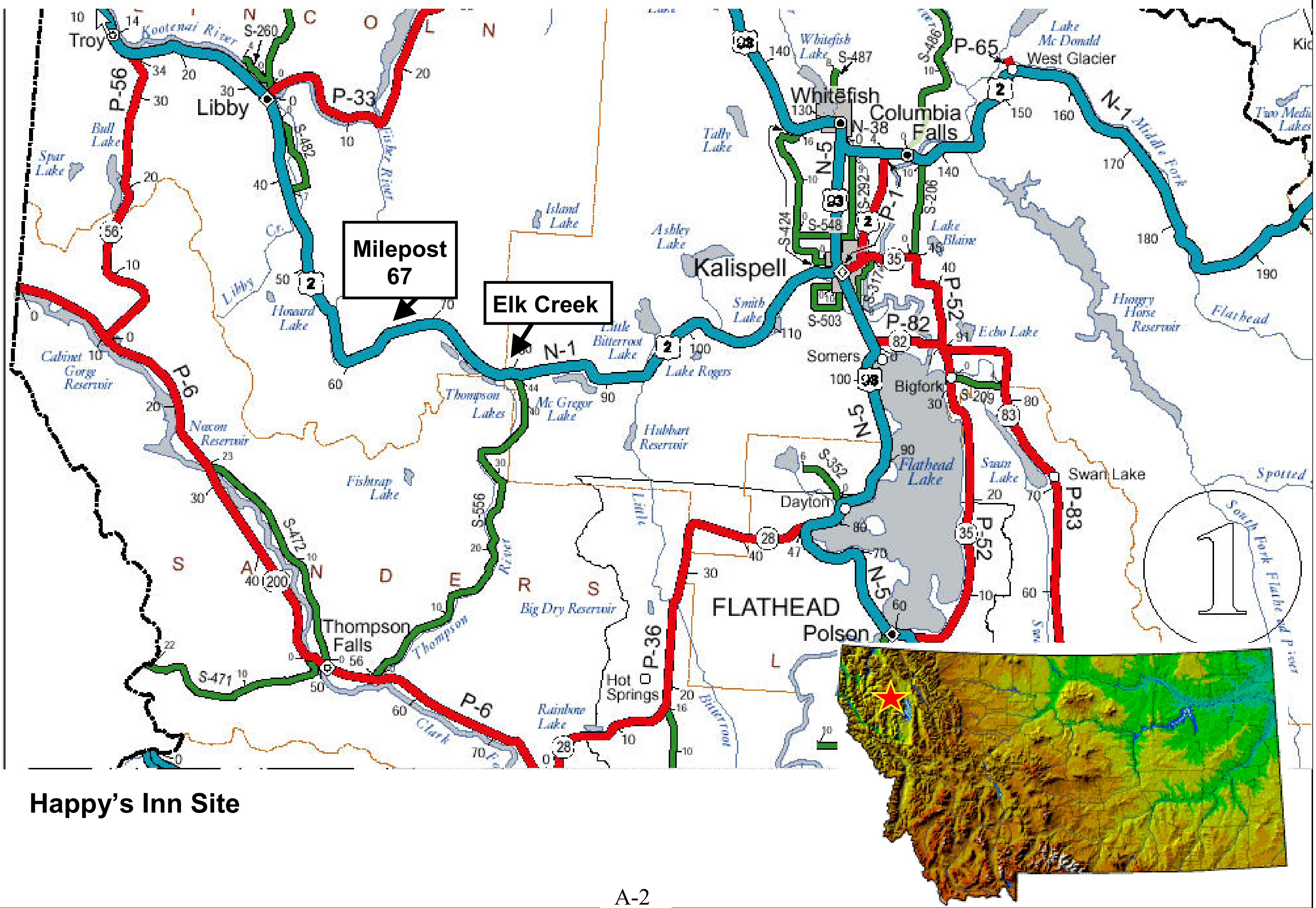
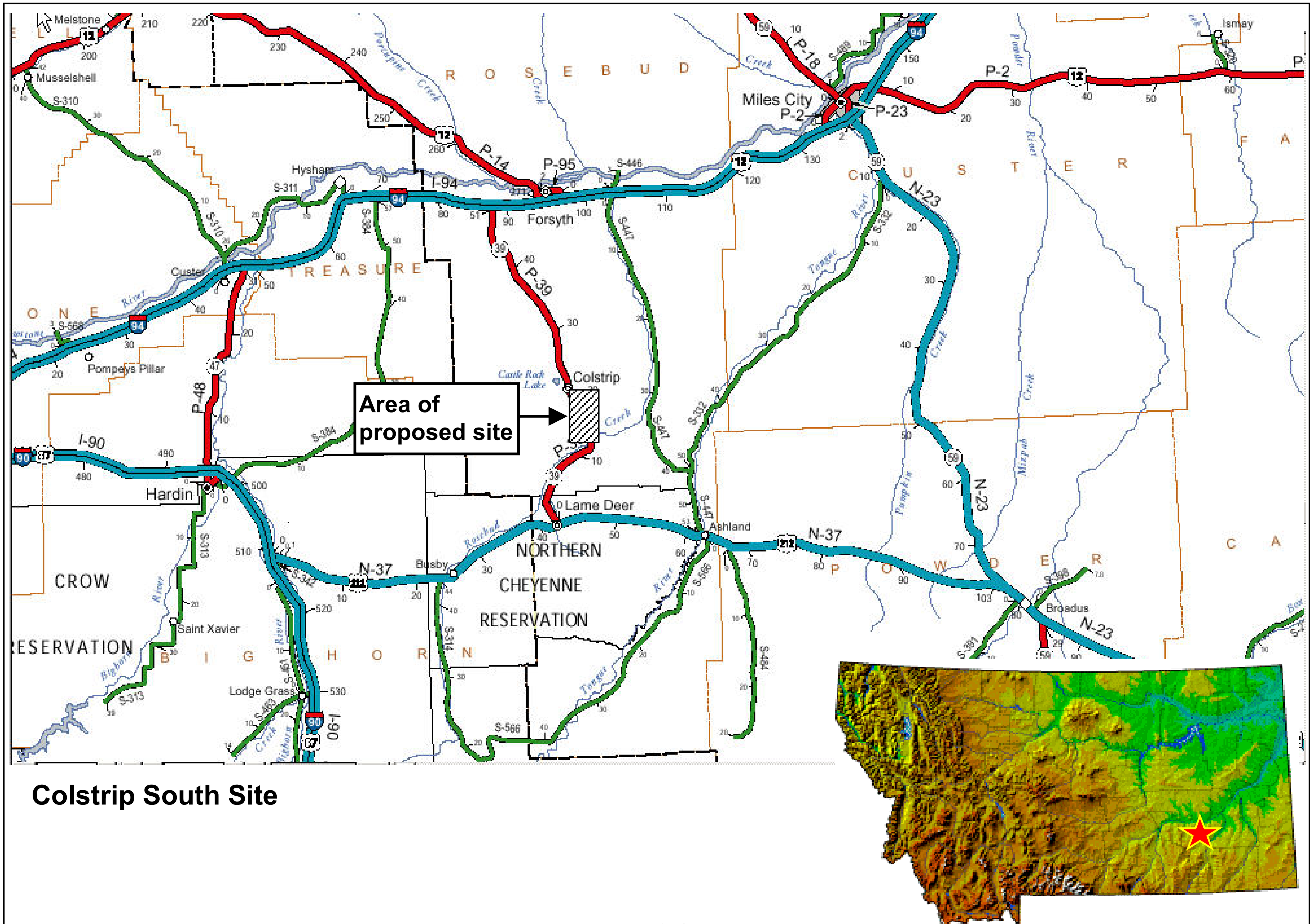
Appendix A Site Maps



Happy's Inn Site



Colstrip South Site

Standard Specification for

Compost for Erosion/Sediment Control (Compost Blankets)

AASHTO Designation: MP-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Compost for Erosion/Sediment Control (Compost Blanket)

AASHTO Designation: MP-10

1. SCOPE

1. 1 This specification covers compost produced from various organic by-products, for use as a surface mulch for erosion/sediment control on sloped areas. This technique may be used for both temporary and permanent erosion/sediment control applications.

1.2 This technique is appropriate for slopes up to a 2:1 grade (horizontal distance : vertical distance), and should only be used in areas that have sheetflow drainage patterns (not areas that receive concentrated flows). This technique may also be used on up to 1:1 slopes with proper consideration to length of slope and compost application rates (depth).

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:

•D 2977, Standard Test Method for Particle Size Range of Peat Materials for Horticultural Purposes.

2.2 US EPA Test Methods:

• US EPA Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. SW-846. 3rd Edition.

2.3 TMECC Sampling and Test Methods:

• The Test Methods for the Examination of Compost and Composting (TMECC), Jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series).

2.4 Other Standards:

• US Composting Council Seal of Testing Assurance Program documents.

Development of Landscape Architecture Specifications for Compost Utilization, The U.S. Composting Council and the Clean Washington Center. 1997.

3. GENERAL DESCRIPTION

3.1. Compost is the product resulting from the controlled biological decomposition of organic material, occurring under aerobic conditions, that has been sanitized through the generation of heat and stabilized to the point that it is appropriate for its particular application. Active composting is typically characterized by a high-temperature phase that sanitizes the product and allows a high rate of decomposition, followed by a lower-temperature phase that allows the product to stabilize while still decomposing at a slower rate. Compost should possess no objectionable odors or substances toxic to plants, and shall not resemble the raw material from which it was derived. Compost contains plant nutrients but is typically not characterized as a fertilizer.

3.2. Compost may be derived from a variety of feedstocks, including agricultural, forestry, food, or industrial residuals; biosolids (treated sewage sludge); leaf and yard trimmings; manure; tree wood; or source-separated or mixed solid waste.

3.3. Proper thermophilic composting, meeting the US Environmental Protection Agency's definition for a 'process to further reduce pathogens' (PFRP), will effectively reduce populations of human and plant pathogens, as well as destroy noxious weed seeds and propagules.

3.4. Compost is typically characterized as a finely screened and stabilized product that is used as a soil amendment. However, most composts also contain a wood based fraction (e.g., bark, ground brush and tree wood, wood chips, etc.) which is typically removed before use as a soil amendment. This coarser, woody fraction of compost plays an important role when compost is used in erosion and sediment control. It is even possible to add fresh, ground bark or composted, properly sized wood based material to a compost product, as necessary, to improve its efficacy in this application.

3.5. Compost products acceptable for this application must meet the chemical, physical and biological properties outlined in section 4.

4. CHEMICAL, PHYSICAL AND BIOLOGICAL PARAMETERS

4.1 Compost products specified for use in this application are described in Table 1. The product's parameters will vary based on whether vegetation will be established on the treated slope.

4.2 Only compost products that meet all applicable state and federal regulations pertaining to its production and distribution may be used in this application. Approved compost products must meet related state and federal chemical contaminant (e.g., heavy metals, pesticides, etc.) and pathogen limit standards pertaining to the feedstocks (source materials) in which it is derived.

Table 1 – Compost Blanket Parameters

Parameters[1,4]	Reported as (units of measure)	Surface Mulch to be Vegetated	Surface Mulch to be left Un-vegetated
pH[2]	pH units	5.0 - 8.5	N/A
Soluble Salt Concentration[2] (electrical conductivity)	dS/m (mmhos/cm)	Maximum 5	Maximum 5
Moisture Content	%, wet weight basis	30 – 60	30 – 60
Organic Matter Content	%, dry weight basis	25 – 65	25-100
Particle Size	% passing a selected mesh size, dry weight basis	• 3" (75 mm), 100% passing • 1" (25mm), 90% to 100% passing • 3/4" (19mm), 65% to 100%passing • 1/4" (6.4 mm), 0% to 75% passing • Maximum particle length of 6" (152mm)	• 3" (75 mm), 100% passing • 1" (25mm), 90% to 100% passing • 3/4" (19mm), 65% to 100%passing • 1/4" (6.4 mm), 0% to 75% passing • Maximum particle length of 6" (152mm)
Stability[3] Carbon Dioxide Evolution Rate	mg CO_2-C per g OM per day	< 8	N/A
Physical Contaminants (man-made inerts)	%, dry weight basis	< 1	< 1

[1] Recommended test methodologies are provided in Test Methods for the Examination of Composting and Compost (TMECC, The US Composting Council)
[2] Each specific plant species requires a specific pH range. Each plant also has a salinity tolerance rating, and maximum
tolerable quantities are known. When specifying the establishment of any plant or turf species, it is important to understand their pH and soluble salt requirements, and how they relate to the compost in use.
[3] Stability/Maturity rating is an area of compost science that is still evolving, and as such, other various test methods could be considered. Also, never base compost quality conclusions on the result of a single stability/maturity test.
[4] Landscape architects and project (field) engineers may modify the allowable compost specification ranges based on specific field conditions and plant requirements.

4.3. Very coarse compost should be avoided if the slope is to be landscaped or seeded as it
will make planting and crop establishment more difficult.

4.4 In regions subject to higher rates of precipitation and/or rainfall intensity, higher compost application rates should be used. In these particular regions, as well as regions subject to wind erosion, coarser compost products are preferred.

Notes: Specifying the use of compost products that are certified by the US Composting Council's Seal of Testing (STA) Program www.compostingcouncil.org) will allow for the acquisition of products that are analyzed on a routine basis, using the specified test methods. STA participants are also required to provide a standard product label to all customers, allowing easy comparison to other products.

Where water quality is an issue, or in areas in proximity to sensitive water bodies, the appropriate compost product should be used, and vegetating the compost blanket should
be considered.

5. FIELD APPLICATIONS

The following steps shall be taken for the proper installation of compost as a soil blanket for erosion/sediment control on sloped areas.

5.1. Slightly roughen (scarify) slopes and remove large clods, rocks, stumps, roots larger than 2 inches in diameter and debris on slopes where vegetation is to be established. This soil preparation step may be eliminated where approved by the Project Engineer or Landscape Architect/Designer, or where seeding or planting is not planned. Where practical, track (compact) perpendicular to contours on the slope using a bulldozer before applying compost as soil blanket.

5.2. Apply compost at the rates specified in Table 2.

Table 2 – Compost Blanket Application Rates

Annual Rainfall/Flow Rate	**Total Precipitation & Rainfall Erosivity Index**	**Application Rate For Vegetated* Compost Surface Mulch**	**Application Rate For Unvegetated Compost Surface Mulch**
Low	1-25”, 20-90	½ - ¾ ” (12.5 mm - 19 mm)	1” – 1 ½” (25 mm – 37.5mm)
Average	26-50”, 91-200	¾ - 1” (19 mm - 25 mm)	1 ½” – 2” (37 mm – 50 mm)
High	51” and above, 201 and above	1-2” (25 mm - 50 mm)	2-4” (50mm – 100mm)

*these lower application rates should only be used in conjunction with seeding, and for compost blankets applied during the prescribed planting season for the particular region.

5.2.1 Compost blanket application rates should be modified based on specific site (e.g., soil characteristics, existing vegetation) and climatic conditions, as well as particular project related requirements. The severity of slope grade, as well as slope length, will also influence compost application rates.

5.2.2. In regions subjected to higher rates of precipitation and/or rainfall intensity, higher compost application rates should be used. In these regions, as well as those with spring snow melt, and on sites possessing severe grades or long slope lengths, the compost blanket may be used in conjunction with a compost filter berm. The filter berm may be 1-2 feet high (30 cm – 60 cm), by 2-4 feet wide (60 cm – 120 cm), and may be placed at the top or base (or both) of the slope. In these particular regions, as well as regions subject to wind erosion, coarser compost products are also preferred.

5.2.3. In regions subject to lower rates of precipitation and/or rainfall intensity, lower compost application rates may be used.

Note: Specific regions may receive higher rainfall rates, but this rainfall is received through low intensity rainfall events (e.g., the Northwestern U.S.). These regions may use lower compost application rates.

5.3. Compost shall be uniformly applied using an approved spreader unit, including bulldozers, side discharge manure spreaders, etc. Alternatively, apply compost using a pneumatic (blower) unit, or other unit that propels the product directly at the soil surface, thereby preventing water from moving between the soil-compost interface. Thorough watering may be used to improve settling of the compost. Apply compost layer approximately 3 feet (90 cm) over the top of the slope, or overlap it into existing vegetation.

5.4. On highly unstable soils, use compost in conjunction with appropriate structural measures.

5.5. Dry or hydraulic seeding may be completed following compost application, as required, or during the compost application itself, where a pneumatic unit is used to apply the compost.

6. TEST METHODS

6.1. The chemical, physical and biological analysis of the compost shall be determined in accordance with the Test Methods for the Examination of Compost and Composting (TMECC), jointly published by the US Department of Agriculture and the US Composting Council (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). (See Appendix A.)

6.2. ASTM D 2977, Standard Test Method for Particle Size Range of Peat Materials for Horticultural Purposes shall be used to determine compost gradation.

7. SAMPLING, INSPECTION, PACKING, AND MARKING

7.1. The sampling, testing, packing, and marking of compost samples shall be done in
accordance with TMECC 02.01-B (Selection of Sampling Locations for Windrows and Piles).

8. KEYWORDS

8.1 Compost, erosion control, sediment control, slope stabilization, sheet flow.

APPENDIX A

(Nonmandatory Information)

A1. METHODS FOR THE SAMPLING AND CHARACTERIZATION OF COMPOST

A1.1. Sampling procedures to be used for purposes of this specification (and the Seal of Testing Assurance program) are as provided in 02.01 Field Sampling of Compost Materials, 02.01-B Selection of Sampling Locations for Windrows and Piles of the Test Methods for the Examination of Compost and Composting (TMECC), Chapter 2, Section One, Sample Collection and Laboratory Preparation, jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). The sample collection section is available online at http://tmecc.org/tmecc/.

A1.2. Test Methods to be used for purposes of this specification are as provided in The Test Methods for the Examination of Compost and Composting (TMECC), Jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). A list of such methods is provided in the table below and online at http://tmecc.org/tmecc/.

Table A – Test Methods for Compost Characterization

Compost Parameters	Reported as	Test Method	Test Method Name
pH		TMECC 04.11-A	Electrometric pH Determinations for Compost. 1:5 Slurry Method
Soluble salts	dS/m (mmhos/cm)	TMECC 04.10-A	Electrical Conductivity for Compost. 1:5 Slurry Method (Mass Basis)
Primary plant nutrients:	%, as-is (wet) & dry weight basis		
Nitrogen	Total N	TMECC 04.02-D	Nitrogen. Total Nitrogen by Combustion
Phosphorus	P_2O_5	TMECC 04.03-A	Phosphorus. Total Phosphorus
Potassium	K_2O	TMECC 04.04-A	Potassium. Total Potassium
Calcium	Ca	TMECC 04.04-Ca	Secondary and Micro-Nutrient Content. Calcium
Magnesium	Mg	TMECC 04.04-Mg	Secondary and Micro-Nutrient Content. Magnesium

Moisture content	%, wet weight basis	TMECC 03.09-A	Total Solids and Moisture at 70±5°C
Organic matter content	%, dry weight basis	TMECC 05.07-A	Matter Method. Loss On Ignition Organic Matter Method
Particle size	Screen size passing through	TMECC 02.12-B	Laboratory Sample Preparation. Sample Sieving for Aggregate Size Classification.
Stability (respirometry)	mg CO_2-C per g TS per day mg CO_2-C per g OM per day	TMECC 05.08-B	Respirometry. Carbon Dioxide Evolution Rate
Maturity (Bioassay) Percent Emergence Relative Seedling Vigor	 % (average) % (average)	TMECC 05.05-A	Biological Assays. Seedling Emergence and Relative Growth

Appendix C Equipment Providers

Potential Applicable Equipment Summary.

Although most applicable existing literature relating to compost incorporation on 50 percent slopes was reviewed for this project, no claim is made that the following listed equipment represents an inclusive list.

Crawler Type Equipment
Caterpillar (http://cmms.cat.com)

Current models of selected Caterpillar crawler units.

Model	Power	Weight	Track on Ground	Track Gauge	Ground Pressure
D3G LPG	52kW (70 hp)	7768 kg (17126 lb)	205.5 cm (81 in)	167.6 cm (66 in)	29 kPa (4.21 psi)
D4G LPG	60kW (80 hp)	8143 kg (17952 lb)	221.1 cm (87 in)	167.6 cm (66 in)	28.3 kPa (4.11 psi)
D5G LPG	67kW (90 hp)	9254 kg (20402 lb)	231.7 cm (91 in)	172.7 cm (68 in)	29.5 kPa (4.28 psi)
D5N LGP	86 kW (115 hp)	12975kg (28606 lb)	260.4 cm (103 in)	200 cm (79 in)	32.8 kPa (4.76 psi)
D6R LPG	138 kW (185 hp)	20700 kg (45600 lb)	?	221 cm (87 in)	?
517	89.5 kW (120 hp)	18364 kg (40450 il)	271 cm (107 in)	?	?
527	112 kW (150 hp)	21477 kg (47250 lb)	284.5 cm (112 in)	?	?

Formerly manufactured Caterpillar tracked agricultural tractors.

Area Caterpillar Dealers:

Tractor and Equipment Company
1835 Harnish Blvd.
Billings, MT 59101-6293
(406) 656-0202

Tractor and Equipment Company
4001 River Drive N.
Great Falls, MT 59405-1020
(406) 761-7900

Western States Equipment Company
3500 Highway 93 South
Kalispell, MT 59901-7907
(406) 752-3030

Western States Equipment Company
3760 N Reserve
Missoula, MT 59808-1518
(406) 721-4050

Wyoming Machinery Company
5505 Mohan Road
Gillette, WY 82718-6959
(307) 686-1500

Western States Equipment Company
520 N Dyer Road
Spokane, WA 99212
(509) 535-2287

John Deere Equipment

Current models of selected John Deere crawler units.

Model	Power	Weight	Track on Ground	Track Gauge	Ground Pressure
450H LPG	55kW (74 hp)	7500 kg (16500 lb)	218.4 cm (86 in)	165 cm (65 in)	27.6 kPa (4.0 psi)
550H LPG	63kW (84 hp)	7437 kg (17500 lb)	218.4 cm (86 in)	175.3cm (69 in)	29.0 kPa (4.2 psi)
650H LPG	67kW (90 hp)	8660 kg (19100 lb)	221 cm (87 in)	175.3 cm (69 in)	27.0 kPa (3.9 psi)
700H LGP	86 kW (115 hp)	12653kg (27900 lb)	260 cm (102 in)	198.1 cm (78 in)	32.0 kPa (4.6 psi)
750C LPG	104 kW (140 hp)	16625 kg (36576 lb)	278 cm (109.5 in)	208.3 cm (82 in)	33.9 kPa (4.9 psi)
850C LGP	138 kW (185 hp)	20222 kg (44582 lb)	307.3 cm (121 in)	223.5 cm (88 in)	31.7 kPa (4.6 psi)

Area John Deere Dealers:

Agricultural Tractors

Belgrade Equipment, LLC
205 Floss Flats
Belgrade, MT 59714
(406) 388-2100

Dillon Implement Company Inc
1025 Selway Drive
Dillon, MT 59725
(406) 683-4281

Moodie Implement Company
Highway 87 West
Lewistown, MT 59457
(406) 538-5434

Crawler Tractors/Logging Equipment

RDO Construction Eq Co MW
5221 Midland Road
Billings, MT 59107
(406) 259-5536

RDO Construction Eq Co MW
4900 Tri Hill Frontage Road
Great Falls, MT 59404-4937
(406) 452-8521

Strong and Bradley
1122 Park Street
Livingston, MT 59047
(406) 222-3150

Yellowstone County Implement
5121 Midland Road
Billings, MT 59101
(406) 248-7787

Western States Equipment Company
520 N Dyer Road
Spokane, WA 99212
(509) 535-2287

Case Construction Equipment

Current models of selected Case crawler units.

Model	Power	Weight	Track on Ground	Track Gauge	Ground Pressure
550H LPG	50kW (67 hp)	6786 kg (14960 lb)	198 cm (78 in)	163cm (64 in)	25.5 kPa (3.7 psi)
650K LPG	55.7kW (74.8 hp)	8813 kg (19400 lb)			
750K LGP	60 kW (81 hp)	9157 kg (20200 lb)			
850K LPG	72 kW (96 hp)	9402 kg (20700 lb)			
1150C LGP	89 kW (119 hp)	12274 kg (27060 lb)	246 cm (97 in)	246 cm (97 in)	28.9 kPa (4.1 psi)
1650K LPG	104 kW (140 hp)	16230 kg (37500 lb)	299 cm (118 in)	214 cm (84.3 in)	30.1 kPa (4.3 psi)
1850K LPG	134 kW (180 hp)	22040 kg (48590 lb)	320 cm (126 in)	233.7 cm (92 in)	37.6 kPa (5.4 psi)

Area Case Construction Equipment Dealers:

Crawler Tractors/Logging Equipment

Western Plains Machinery Company
1215 38th Street North
P.O. Box 2507
Great Falls, MT 59401

Kamp Implement Company
6855 Jackrabbit Lane
Belgrade, MT 59714
Specialized Wheel Tractors
AEBI (http://www.aebi-us.com)

Current and former AEBI tractor models

Model	Power (kW/hp	Weight (kg/lb)	Steering (2 wheel or 4 wheel)	Transmission Manual (M) or Hydrostatic (H)
TT40	26.5/36	1220/2690	2	M, 8/8
TT50	33.0/45	1400/3087	2	M, 8/8
TT60	34.0/46	1480/3263	4	H
TT70	41.0/56	1560/3440	4	H
TT70S	44.5/61	1560/3440	4	H
TT75	Spec. unavailable	Spec. unavailable	4	H
TT77	?	?	2	M
TT80	36.6/50	1720/3793	2	M, 8/8, 12/12 opt
TT88	44.0/60	?	2	M,H
TT90	47.0/64	1880/4145	2	H
TT95	60.2/82	1950/4300	2	H

AEBI North America, Inc.
1823 North Hamilton Street
Richmond, VA 23230
(888) 729-2324

Peterson Equipment Company
P.O. Box 6070
2685 North Main
Logan, UT 84341
(435) 752-5110
(435) 752-8696

Snow Cats/Utility Vehicles

Peterson Equipment Company is also the area dealer for both PistenBully (PistenBully Model 100 All Season) and LMC snow cats and utility vehicles.

Tucker Terra

Tucker Sno-Cat Corporation
P.O. Box 1529
Medford, OR 97501
(541) 779-3731