EVALUATION OF ORGANIC MATTER ADDITION AND INCORPORATION ON STEEP CUT SLOPES: *PHASE II TEST PLOT CONSTRUCTION AND PERFORMANCE MONITORING*

FHWA/MT-07-001/8176

Final Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

April 2007

prepared by
S.R. Jennings
J.D. Goering
P.S. Blicker

Research Reclamation Unit
Montana State University - Bozeman

RESEARCH PROGRAMS

Montana Department of Transportation
serving you with pride

EVALUATION OF ORGANIC MATTER ADDITION AND INCORPORATION ON STEEP CUT SLOPES

Phase II: Test Plot Construction and Performance Monitoring

Prepared For:

Montana Department of Transportation
P.O. Box 201001
Helena, MT 59620-1001

Prepared By:

Reclamation Research Unit
Department of Land Resources and Environmental Sciences
Montana State University
Bozeman, MT 59717-2910

April 2007

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
FHWA/MT-07-001/8176

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
EVALUATION OF ORGANIC MATTER COMPOST ADDITION AND INCORPORATION ON STEEP CUT SLOPES, Phase II: Test Plot Construction and Performance Monitoring

5. Report Date
April 2007

6. Performing Organization Code

7. Author(s)
S. R. Jennings, J.D. Goering, and P.S. Blicker

8. Performing Organization Report No.

9. Performing Organization Name and Address
Reclamation Research Unit
Montana State University
106 Linfield Hall
Bozeman, MT 59717

10. Work Unit No.

11. Contract or Grant No.
MDT #8176 / MSU #425196

12. Sponsoring Agency Name and Address
Research Programs
Montana Department of Transportation
2701 Prospect Avenue
PO Box 201001
Helena MT 59620-1001

13. Type of Report and Period Covered
Phase II Final Report

August 2003 – November 2006

14. Sponsoring Agency Code
5401

15. Supplementary Notes **Research performed in cooperation with the Montana Department of Transportation and the US Department of Transportation, Federal Highway Administration. This report can be found at http://www.mdt.mt.gov/research/projects/env/organic_matter.shtml.**

16. Abstract

Erosion of steep highway cut slopes in Montana is often times 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. Topsoil is often locally unavailable. The overall research objectives for this project were to: 1) Reduce sediment yield and erosion from steep highway cut slopes through amendment with compost; 2) Enhance vegetation establishment on steep highway cut slopes through amendment with compost; 3) Develop amendment rates, application protocols and techniques for compost addition and incorporation on steep highway cut slopes; 4) Implement, monitor and evaluate test plots on steep highway cut slopes; and 5) Communicate, report and provide technology transfer of the research findings. The subject of this report is performance monitoring of research plots during the 2004-2006 period.

17. Key Words
Compost, steep slope, revegetation

18. Distribution Statement
Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	100	

DISCLAIMER STATEMENT

This document is disseminated under the sponsorship of the Montana Department of Transportation and the United States Department of Transportation in the interest of information exchange. The State of Montana and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policies of the Montana Department of Transportation or the United States Department of Transportation.

The State of Montana and the United States Government do not endorse products of manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the content of this document.

This report does not constitute a standard, specification, or regulation.

ALTERNATIVE FORMAT STATEMENT

MDT attempts to provide accommodations for any known disability that may interfere with a person participating in any service, program, or activity of the Department. Alternative accessible formats of this information will be provided upon request. For further information, call (406) 444-7693, TTY (800) 335-7592, or Montana Relay at 711.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS- Continued

LIST OF FIGURES

Page

LIST OF FIGURES - Continued

Page

LIST OF TABLES

Page

LIST OF APPENDIX TABLES and FIGURES

Page

LIST OF APPENDIX TABLES and FIGURES - Continued

Page

1.0 INTRODUCTION

Successful steep slope reclamation associated with highway construction has proven difficult under a number of different geologic and climatic conditions. Failure to establish a robust, self-perpetuating vegetation community leads to increased maintenance costs and, in a number of cases, water quality problems due to storm water run-off. Several studies have revealed the positive effects organic matter addition can have in situations where vegetation establishment has shown to be difficult (U.S. EPA, 1997, Demars and Long, 1998). When present in the soil profile, organic matter tends to enhance infiltration of precipitation, nutrient availability, water holding capacity and soil structure development. However, when sufficient levels of organic matter are absent in the soil profile, vegetation establishment is an on-going challenge.

In Montana, several types of geologic parent material have been identified that cause recurrent maintenance problems for the Montana Department of Transportation (MDT) when encountered on steep cut slopes. Alluvial rock, glacial till and marine shale have proven difficult to revegetate in a number of locations. Glacial till and alluvial rock are common in western Montana while marine shale is common in eastern Montana. In all three cases limited vegetation develops following seeding into these nutrient poor parent materials. Significant erosion problems are generally a result of poor vegetation development on steep slopes, especially from the glacial till and marine shale deposits. Roadside ditches may become clogged with eroded sediment leading to increased maintenance costs and long-term concern for road base stability. Road base aggregate can become saturated as drainage ditches fail to operate properly leading to frost heaving of bituminous overlays.

Departments of Transportation across the country have encountered similar problems to those faced in Montana. Addition of compost has been successfully employed in several States to mitigate steep slope erosion problems along highway corridors. Significant and relevant research investigations have been conducted in California, Connecticut, Idaho, Iowa and Texas that demonstrate the effectiveness of compost addition. Findings from these investigations show that compost addition is an effective, permanent solution to controlling erosion on steep cut slopes (Glanville et al., 2003, Demars and Long, 1998, Idaho Department of Transportation, 1997, Texas Transportation Institute, 1995, Sollenger, 1987). The U.S. Environmental Protection Agency has recently embraced compost-based techniques for use as Best Management Practices (BMPs) for stormwater control including the use of compost blankets (U.S. EPA, 2006).

This project was separated into two phases. Phase I has been completed and consisted of two primary tasks: 1) a review of literature to determine optimum rates of organic compost addition to steep cut slopes, and 2) identification of potential equipment capable of applying and incorporating the compost to a depth of 10 cm (4 in.) on 2H:1V slopes. Site reconnaissance of candidate field research sites for the second phase of the project was also completed (Jennings et al., 2003). For this study steep cutslopes are meant to represent newly exposed parent material. They lack organic material, but root growth is unrestricted.

Phase II consisted of two tasks: 1) evaluation of the efficacy of the application/ incorporation equipment, and 2) measurement of vegetation performance and observations of erosional stability. Monitoring of research plots constructed occurred between 2004 and 2006. The findings from Phase II are the subject of this report.

1.1 Objectives

The overall research objectives for the project are to develop recommendations to:

- Reduce sediment yield and erosion from newly created steep highway cut slope faces through amendment with compost;
- Enhance vegetation establishment and survival on steep highway cut slopes through amendment with compost;
- Evaluate compost application rates, application protocols and techniques for compost addition and incorporation on steep highway cut slopes;
- Monitor and evaluate vegetation conditions and erosion levels on test plots on steep highway cut slopes; and
- Communicate, report and provide technology transfer of the research findings.

The specific objectives of each phase were:

Phase I

- Conduct a review of relevant scientific literature with respect to organic matter amendment addition to enhance plant growth media, and an assessment of their applicability to conditions in Montana;
- Investigate methods for organic matter application and incorporation to steep slope areas (greater than 33 percent) through literature review and correspondence with equipment manufactures and contractors; and
- Integrate knowledge gained into a proposal for Phase II.

Phase II

- Construct test plots on steep highway cut slopes with erosive and/or poorly vegetated parent material;
- Evaluate equipment and develop protocols for application and incorporation of compost on steep cut slopes;
- Monitor and evaluate test plots on steep highway cut slopes; and
- Communicate, report and provide technology transfer of the research findings.

1.2 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 cut slopes prevents practical replacement of salvaged topsoil with conventional equipment. The current remedy is simply to broadcast seed and/or hydromulch bare slopes. 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.

Amendment of steep cut slopes with organic matter may lead to improved vegetation condition, decreased erosion and reduced maintenance cost.

2.0 RESEARCH SITE SELECTION

One of the objectives for this research project was to investigate the application and incorporation of compost on steep cut slopes on three general types of geologic materials including:

1. Coarse textural class valley fill/glacial outwash type materials;
2. Fine textural class materials derived from glacial silt, lake bed sediments and loess; and
3. Fort Union Group shale units typical of eastern Montana plains.

All of these soil materials are encountered by the Montana Department of Transportation (MDT) on steep slopes during roadway construction and reconstruction. All have previously been shown to be difficult to revegetate leading to increased maintenance costs and increased potential for degradation of surface waters by erosion and sedimentation.

2.1 Happys Inn Research Sites

Happys Inn is located between Libby and Kalispell on U.S. Highway 2. Reconstruction of U.S. Highway 2 in 2000 created long steep road cuts in a previously glaciated terrain. The resulting roadcuts were built in glacial till, lacustrine sediment, glacial outwash and sand. Limited vegetation growth and accentuated erosion had been observed since construction.

An initial site reconnaissance was conducted May 6-7, 2003, when two sites were tentatively selected at Mile Posts (MP) 67 and 69 on U.S. Highway 2, approximately 37 miles (60 km) east of Libby, Montana (Figure 1). The MP 67 site was comprised of glacial till with abundant boulders and cobbles in a fine textured matrix. This site was highly eroded and over steepened. Gullies up to approximately 1 m (3.3 ft) deep were present. Regrading the slope would have been required to eliminate the rills and gullies and to return the slope to a 50 percent gradient. Subsequent discussions indicated that the resources to regrade and remove several thousand cubic meters of material were not available and an alternative site was selected at MP 77 (Middle Thompson Lake). Although the MP 77 site was less steep than the desired 50 percent slope, it was composed of fine textured glacial lakebed soils that have proven very difficult to successfully revegetate. Materials at the MP 69 site (Loon Lake) were very coarse textured and required no regrading.

2.1.1 Physiographic Conditions

Both research sites are in the forested, mountainous terrain of northwestern Montana. Elevations range from about 1012 m (3320 feet) at the outlet of Loon Lake to 1841 m (6040 feet) at nearby Rogers Mountain. Drainage into and out of Loon Lake is via the Fisher River that flows west and north to a confluence with the Kootenai River west of Libby, Montana. Drainage from Middle Thompson Lake flows to Lower Thompson Lake, the headwater of the Thompson River and thence to the confluence with the Clark Fork River near Thompson Falls, Montana.

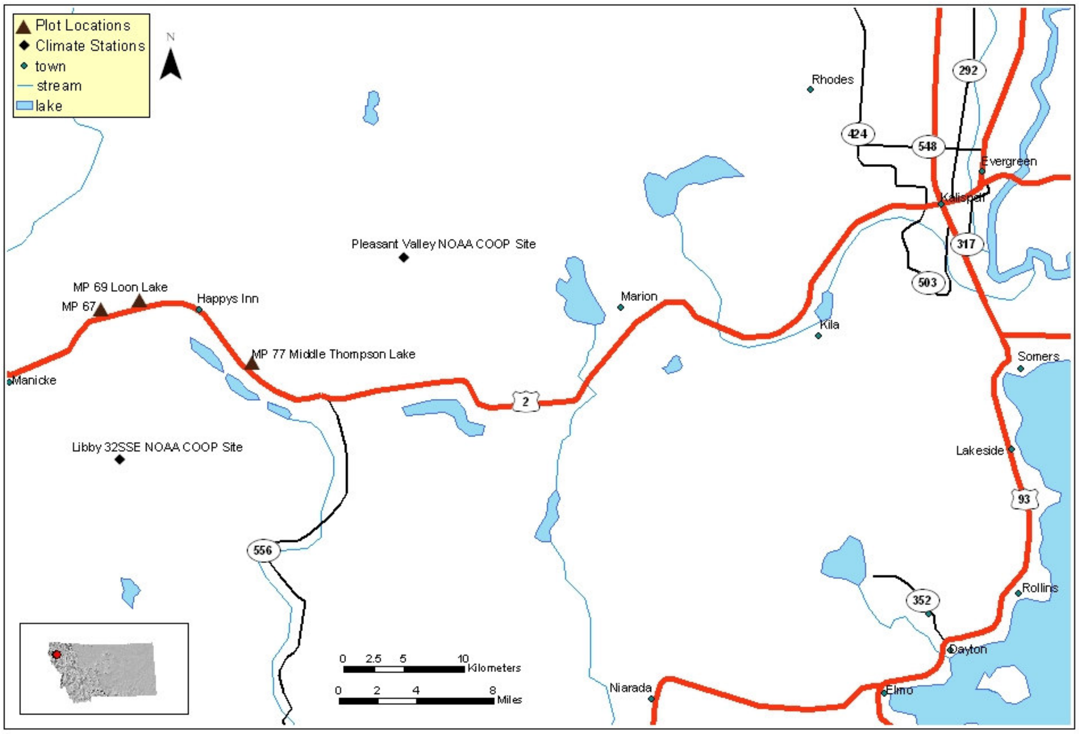


Figure 1. Happys Inn research site locations.

The area is underlain by Belt Group metasedimentary rocks, including the Wallace Formation, Missoula Group and Ravalli Group (Ross et al., 1955). Much of the present topography is the result of both local and cordilleran glaciation (Alden, 1953). Morainal debris, till, outwash and lake sediments are present in the vicinity and exposed in numerous cut slopes along U.S. Highway 2.

2.1.2 Climatic Conditions

Climatic data is available from two stations near the research sites: 1) Libby 32 SSE (station 245020), and 2) Pleasant Valley (station 246576). These stations are approximately 8 miles (13 km) southwest and 10 miles (16 km) northeast of the research sites respectively (Figure 1). Elevation at both of these climatic stations is 1097 m (3599 ft) versus approximately 1036 m (3399 ft) at the research sites. The distribution of annual precipitation is very similar at the two climatic stations.

Approximately 60 percent of the precipitation occurs during the October through March period with January receiving the greatest monthly precipitation for the year. June receives the greatest precipitation during the growing season, while July, August, and September are the driest months of the year (Figure 2). Most precipitation in the November through April period occurs as snowfall with some accumulated snow depth occurring during these months. Mean annual precipitation for the Libby 32 SSE climate station is 63.4 cm (24.96 inches) while the Pleasant Valley station reports 47.7 cm (18.78 inches) of annual precipitation.

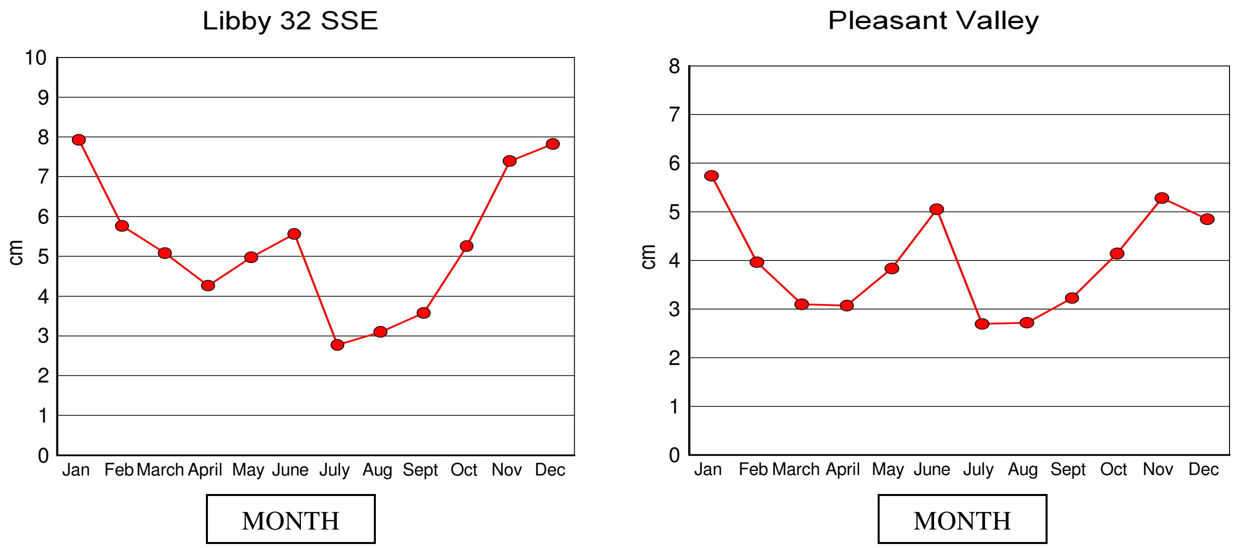


Figure 2. Monthly precipitation for NOAA stations 245020 (Libby 32 SSE) and 246576 (Pleasant Valley).

The mean annual temperature at the two NOAA sites is 4.7 degrees C (40.5 degrees F). Average maximum temperatures range from -1.2 degrees C (29.9 degrees F) in January to 26.1 degrees C (79.1 degrees F) in July. Average minimum temperatures remain less than 0° C in the October through April period (Figure 3).

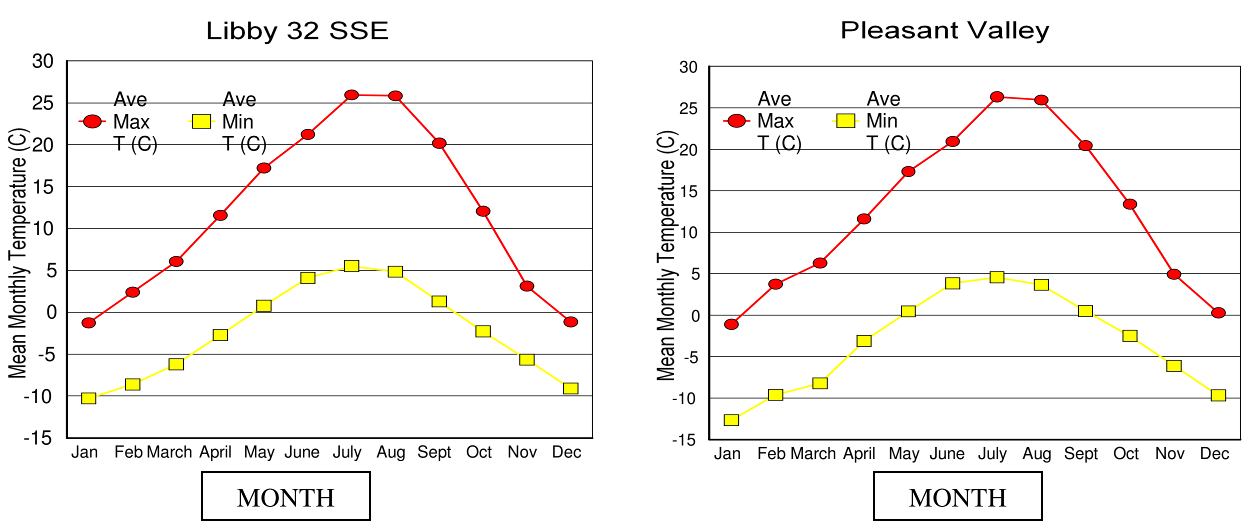


Figure 3. Mean monthly maximum and minimum temperatures at climate stations near the Happys Inn research sites.

The MAPS program (Caprio et al., 2001) was used to estimate monthly evapotranspiration (Figure 4). All values for the two sites were identical except for September, with July and August exhibiting the greatest evapotranspiration rates of 14.5 and 11.7 cm (5.7 and 4.6 inches), respectively. Potential evapotranspiration is notably greater than mean monthly precipitation during July and August.

In general, precipitation should not be limiting at either of the Happys Inn research sites. However, the combination of south aspects; droughty soil conditions caused by either excessive runoff (silt dominated site) or low water holding capacity (sand and rock dominated site); low growing season precipitation during July, August and September; and moderately high evapotranspiration rates in July and August has the potential to produce conditions unfavorable for plant development.

2.1.3 Existing Vegetation

Vegetation in areas adjacent to the highway cut slopes selected for this study consists of typical forest community species found in northwestern Montana. The coniferous over-story is dominated by Douglas fir (*Pseudotsuga menziesii,* scientific nomenclature after The Plants Database[1]*),* western larch (*Larix occidentalis*), and ponderosa pine (*Pinus ponderosa*) while the under-story contains many forbs, grass and shrubs. Most, if not all, adjacent areas have been logged at least once. Many of the native species would be difficult to establish on the generally south aspect steep cut slopes that lack organic matter. Virtually none of the native species had volunteered on the cut slopes at the research sites constructed in 2000. Noxious weeds have begun to encroach along the margins of the sites, especially spotted knapweed *(Centaurea stoebe*).

Vegetation conditions at the Loon Lake site (MP 69) prior to implementation of the compost treatments are presented in Table 1. The Middle Thompson Lake site was essentially barren of any vegetation. Table 2 reports the ground cover observed at both research sites prior to treatment.

---

[1] USDA, NRCS. 2006. The PLANTS Database (http://plants.usda.gov, 26 December 2006). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

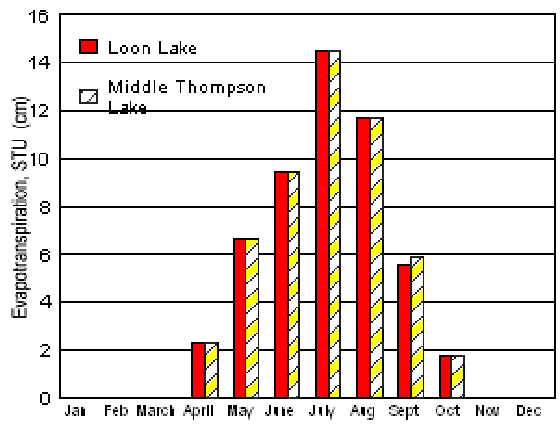


Figure 4. Mean monthly evapotranspiration for Happys Inn research sites. Values determined by Caprio (1971) solar-thermal unit method.

Table 1. Species composition and abundance at the Loon Lake research site (MP 69) prior to treatment.

Common Name	Scientific Name	Abundance
Sheep fescue*$	*Festuca ovina*	+
Slender wheatgrass**$	*Elymus trachycaulus*	-
Sweetclover	*Melilotus* spp.	-
Spotted knapweed	*Centaurea stoebe*	-
Alfalfa	*Medicago sativa*	#
Common mullein	*Verbascum thapsus*	#
Canada wildrye$	*Elymus Canadensis*	#
Blue flax	*Linum lewisii*	#
Lodgepole pine	*Pinus contorta*	#

+ = 2 to 5% canopy cover class
- = 1 to 2% canopy cover class
= < 1% canopy cover class
* Sheep fescue comprises 90% of plant density and canopy coverage. The fescue averages about 3 plants per square foot across all plots. Stunted growth was observed - diameter of leaf spread across canopy averages 2 to 5 inches.
** Wheatgrass species, primarily slender wheatgrass, represents about 1 plant per square foot across all plots with only 1 to 3 culms [stems] per plant.
$ Seeded species included in the original seed blend applied following construction.

Table 2. Ground cover observed at both Happys Inn research sites prior to treatment.

Vegetation and Rock Cover Observed	Loon Lake Distribution	Middle Thompson Lake Distribution
Total plant canopy cover [all species]	8%	<1%
Basal cover [all species]	1.5%	<1%
Ground litter cover	1.0%	<1%
Rock cover: <0.5 inch diameter	25%	<5%
Rock cover: 0.5 - 2 inch diameter	55%	0
Rock cover: 2-6 inch diameter	15%	0
Rock cover: > 6 inch diameter	3%	0

2.1.4 Experimental Design

Five research plots have been established at both MP 69 and MP 77 sites that represent two of the three types of geologic materials desired for this study (Table 3). Treatments included:

- Tillage and broadcast seeding only (controls);
- 2.5 cm (1 in) compost application incorporated to 10 cm (4 in), broadcast seeding;
- 5.1 cm (2 in)compost application incorporated to 10 cm (4 in), broadcast seeding;
- 2.5 cm (1 in) compost application (blanket), broadcast seeding; and
- 5.1 cm (2 in) compost application (blanket) with broadcast seeding.

2.1.5 Research Plot Construction

The experimental design for this project seeks to evaluate both the equipment used for application and incorporation of compost on steep slopes and to subsequently evaluate the effect of the compost treatments on vegetation performance. The following subsections describe the implementation of study sites at MP 69 (Loon Lake) and MP 77 (Middle Thompson Lake).

All compost application was completed using a blower truck (Express Blower/Rexius Model EB-30). Compost thickness was monitored during the application process so that an even distribution of compost was achieved on each treatment plot. Because of scheduling problems, all compost application was completed prior to any incorporation or tillage. Hence, the compost blanket treatments (plots 4, 5, 9 and 10) were placed directly on the untilled substrate. All other plots were chisel plowed. A considerable amount of additional plot tillage was provided by the snowcat track grousers.

Table 3. Plot treatments for the MP 69 and MP 77 research sites.

Site	Plot Number	Treatment	Mean Overall Gradient (%)	Mean Slope Length (m)
MP 77 Middle Thompson Lake Lakebed Silt Dominated Material	1	Control, no compost, chisel plowed	34.5	18.3
	2	2.54 cm compost, incorporated with chisel plow	34.0	17.4
	3	5.08 cm compost, incorporated with chisel plowed	35.0	17.2
	4	2.54 cm compost blanket	37.0	19.8
	5	5.08 cm compost blanket	38.0	15.9
MP 69 Loon Lake Coarse Textural Class Material	6	Control, no compost, chisel plowed	49.0	15.2
	7	2.54 cm compost, incorporated with chisel plow	48.5	15.2
	8	5.08 cm compost, incorporated with chisel plow	45.0	15.2
	9	2.54 cm compost blanket	43.5	15.2
	10	5.08 cm compost blanket	44.0	15.2

2.1.5.1 MP 69 (Loon Lake) Research Site

The MP 69 site is located on the north side of U.S. Highway 2 immediately northwest of Loon Lake (Figure 5). The site is characterized by very coarse textural class material with abundant boulders and cobbles (Figure 6). Mean rock content (> 2 mm) was 63.5 percent (Table 4). All plots at this site were 15.24 m (50 ft) on each side (232.2 m^2 ; 2500 ft^2) with 3 m (10 ft) buffer zones between plots (Figure 7).

Compost was applied at this site on October 21, 2003. Due to the very coarse texture, no prior tillage of this site was deemed necessary. Seed was broadcast at a rate of 39 kg/ha (34.8 lbs/ac). Plots 7 and 9 received 2.5 cm (1 inch) compost blankets while plots 8 and 10 received 5.1 cm (2 inch) blankets. Plots 6, 7 and 8 were chisel plowed on October 23, 2003.

Figure 5. Location of MP 67 (Loon Lake) research site.

Figure 6. MP 69 (Loon Lake) research area preconstruction conditions, Plot 8.

Table 4. MP 69 (Loon Lake) preconstruction physical site characteristics.

Plot	Treatment	Mean Overall Gradient (%)	Mean Slope Length (m)	Rock Content > 2mm (%, mass basis[1])	USDA Textural Class[2]
6	Control, no compost	49.0	15.2	70.9	Sandy loam
7	2.54 cm compost, incorporated	48.5	15.2	62.6	Sandy loam
8	5.08 cm compost, incorporated	45.0	15.2	66.0	Sandy loam
9	2.54 cm compost blanket	43.5	15.2	47.7	Loamy sand
10	5.08 cm compost blanket	44.0	15.2	70.5	Sandy loam

[1] Cobble and boulder materials were not included in collected samples and therefore actual rock content is greater than the stated value.

[2] ASTM 422-63 (2002)

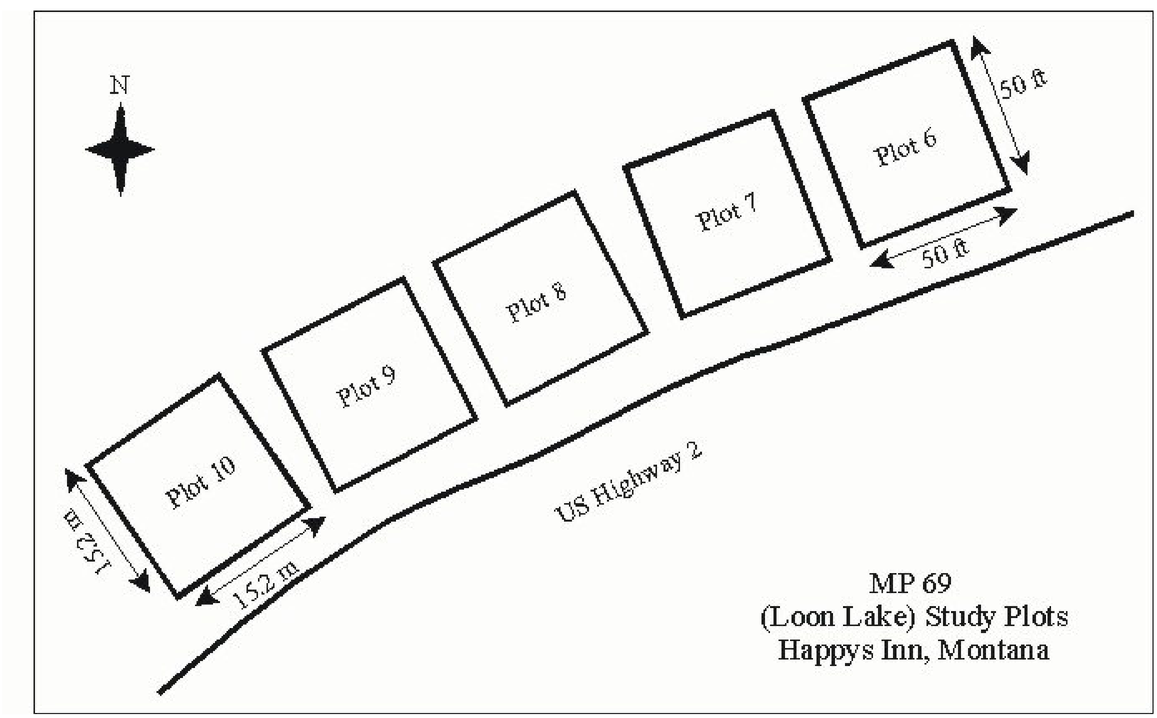


Figure 7. Research plot layouts at the MP 69 site.

2.1.5.2 MP 77 (Middle Thompson Lake) Research Site

The MP 77 site is located along the north side of U.S. Highway 2 adjacent to Middle Thompson Lake (Figure 8). Geologic materials consist of fine textural class sediments that are assumed to be glacial lake sediments. Alden (1953) stated that *"Cuts on the new grade of U.S. Highway No. 2 along the north side of the Thompson Lakes, examined in June 1937, gave fine exposures (at about 3,400 ft* [1036 m] *above sea level) of 20 to 25 ft* [6.1-7.6m] *of finely laminated buff to brownish, rather plastic lacustrine silt. In some of the cuts in these beds have been disturbed by slumping and in some the silt overlies gravel. The silt was evidently deposited in a glacial lake bordering the front of the melting Cordilleran ice."* Typically, these materials have very little rock content (Table 5). The lacustrine silts have proven troublesome to revegetate following construction and vegetation was sparse at this site with a notable accumulation of sediment in roadway drainage ditches (Figure 9). One of the primary erosion mechanisms occurring in these silts appears to be the slumping of saturated surface layers that overlie frozen substrate during spring thaw cycles.

Research plots at this site are 12.2 m (40 ft) wide with lengths ranging from 17.2 to 19.8m (56 to 65 ft). All buffer strips are 3 m (10 ft) except that between plots 2 and 3 the buffer strip is 9.1 m (30 ft) wide (Figure 10). The extra width of the buffer between plots 2 and 3 was included to avoid an area that had some established vegetation and which also would have resulted in a short plot length. The mean plot area at this site is 215.9 m^2 (2324 ft^2).

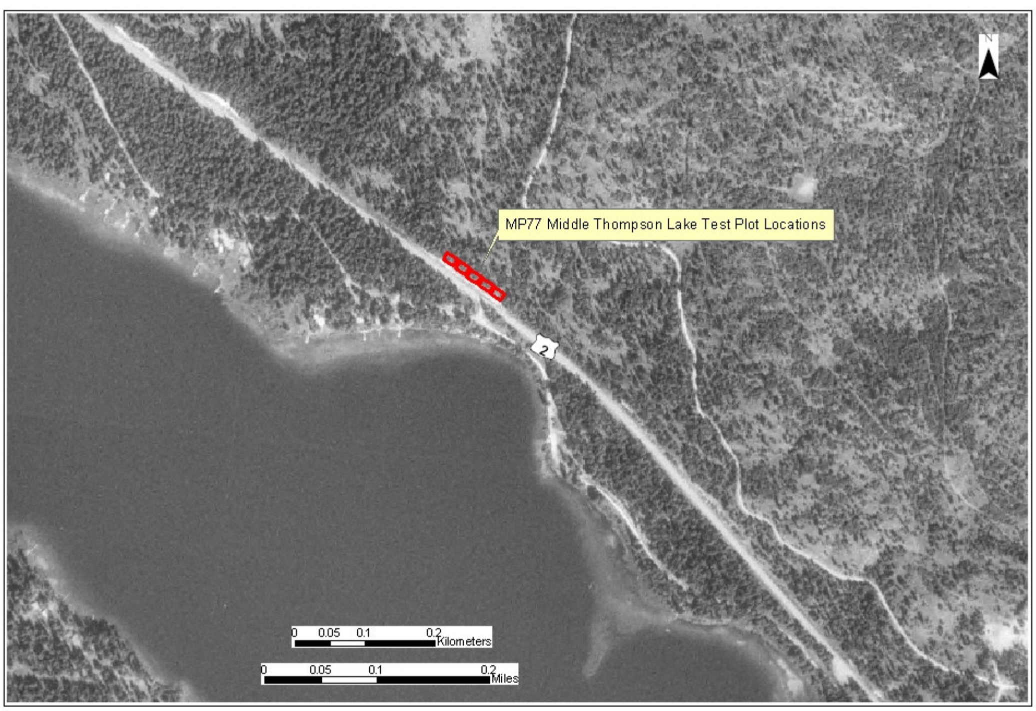


Figure 8. Location of research plots at MP 77 site, adjacent to Middle Thompson Lake.

Table 5. MP 77 (Middle Thompson Lake) preconstruction physical site characteristics.

Plot	Treatment	Mean Overall Gradient (%)	Mean Slope Length (m)	Rock Content > 2mm (%, mass basis)	USDA Textural Class[1]
1	Control, no compost	34.5	18.3	1.2	Silt loam
2	2.54 cm compost, incorporated	34.0	17.4	0.19	Silt loam
3	5.08 cm compost, incorporated	35.0	17.2	0.66	Silt
4	2.54 cm compost blanket	37.0	19.8	5.11	Silt loam
5	5.08 cm compost blanket	38.0	15.9	1.81	Silt loam/Silt

[1] ASTM 422-63 (2002)

Figure 9. Research Plot 1 at the MP 77 site prior to plot implementation. Note accumulated sediment in ditch, rills and the general lack of vegetation cover.

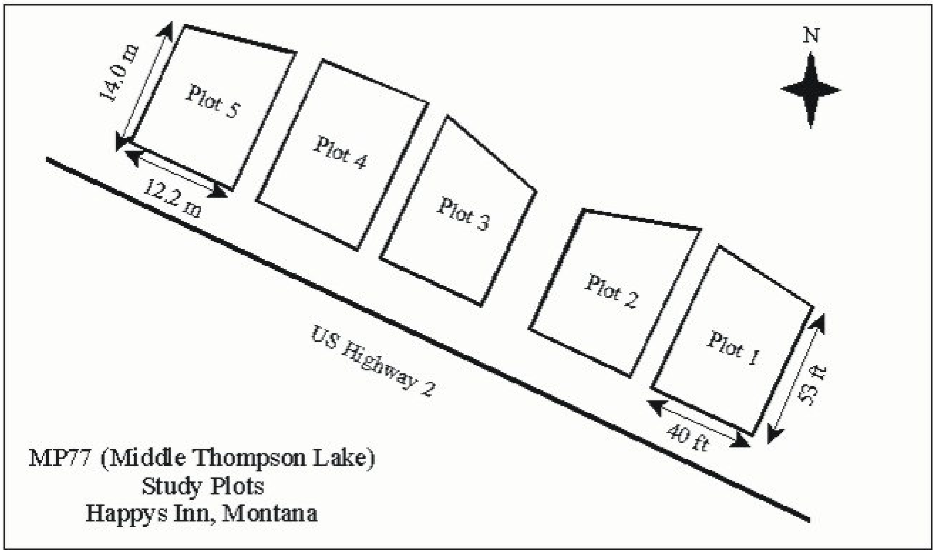


Figure 10. Plot layout at the MP 77 research site.

2.1.5.3 Seeding

All plots at both MP 69 and MP 77 were seeded with the same seed mix (Table 6) which was obtained from Bruce Seed Farm, Inc. located near Townsend, Montana. Seed was applied using a hand operated broadcast seeder at a total rate of 0.91 kg (2 lbs) per plot. This rate is the approximate equivalent of 39 kg/ha (34.7 lbs/ac). The seed was applied in two applications, the first on bare substrate and the second following application of 1.3 cm (0.5 inch) of compost over the first seed application. The remaining compost was applied over the second seed application. The seeding scenario acknowledges the fact that a portion of the applied seed will be placed deeper than desired and therefore this portion may have poor emergence. An extra 0.45 kg (1 lb) of seed was specifically applied to plot 7 at MP 69 following tillage. This was done due to a large disturbance to a portion of this plot that occurred when a track broke on the snowcat during the tillage operation. The seed mix was free of noxious or restricted weed seed. Since no compost was applied to the control plot, seed was applied by a hand broadcast seeder directly to the mineral soil following tillage. The control typifies the seeding technique most commonly used on previous highway construction projects.

2.1.5.4 Compost Mixing

A preliminary evaluation of the effectiveness of the methods used to incorporate compost suggests that incorporation/mixing on the fine textured lake bed sediments at MP 77 was very good. A combination of the tilling action of the snowcat grousers and the chisel plow resulted in a relatively uniform incorporation depth with very little unmixed compost visible. Effective tillage depth was close to the desired 10 cm (4 inch). Incorporation on the coarse textured materials at MP 69 was inconsistent, due in large part to the difficulty of controlling the equipment as it rode over boulders. In areas were traction was lost, the snowcat grousers moved much material down hill creating mixed zones notably deeper than the desired 10 cm (4 inch). In the “spin out” areas where the material was removed, little compost remained. There were areas near the top break of slope where the chisel plow was ineffective due to the limitations of the 3-point hitch which pulled the plow out of the substrate as the front of the snowcat nosed down on the more level terrain above the cut slope. This may not be a problem on longer slopes where the area affected by the radical break in slope would comprise only a small portion of the total area.

Table 6. Seed mix species used at the MP 69 and MP 77 research sites.

Common Name	**Variety**	**Species**	**Percent of Mix (*pure live seed* basis)**
Slender wheatgrass	Pryor	*Elymus trachycaulus* ssp. *trachycaulus*	7.62
Hybrid wheatgrass	Newhy R/S	*Elymus hoffmanii*	20.65
Canada wildrye	V.N.S.	*Elymus canadensis*	12.70
Mountain brome	Bromar	*Bromus marginatus*	12.18
Bluebunch wheatgrass	Goldar	*Pseudoroegneria spicata* ssp. *spicata*	12.70
Big bluegrass	Sherman	*Poa ampla*	2.66
Green needlegrass	Lodorm	*Nassella viridula*	7.38
Streambank wheatgrass	Sodar	*Elymus lanceolatus* ssp. *psammophilus*	12.85
Sheep fescue	Covar	*Festuca ovina*	2.61

2.2 Miles City Research Area

A research site was selected at the junction of I-94 and U.S. Highway 12, approximately 3 miles (4.8 km) east of Miles City, Montana (Figure 11). Initial reconnaissance of this site was conducted March 31, 2004. Considerable effort was expended in an attempt to employ a private contractor for seedbed tillage and these efforts were unsuccessful. The specialized equipment required and the small size of the research project were thought to be factors in the lack of interest from the private sector. The work was completed by Reclamation Research Unit staff and rented equipment as detailed in the following sections.

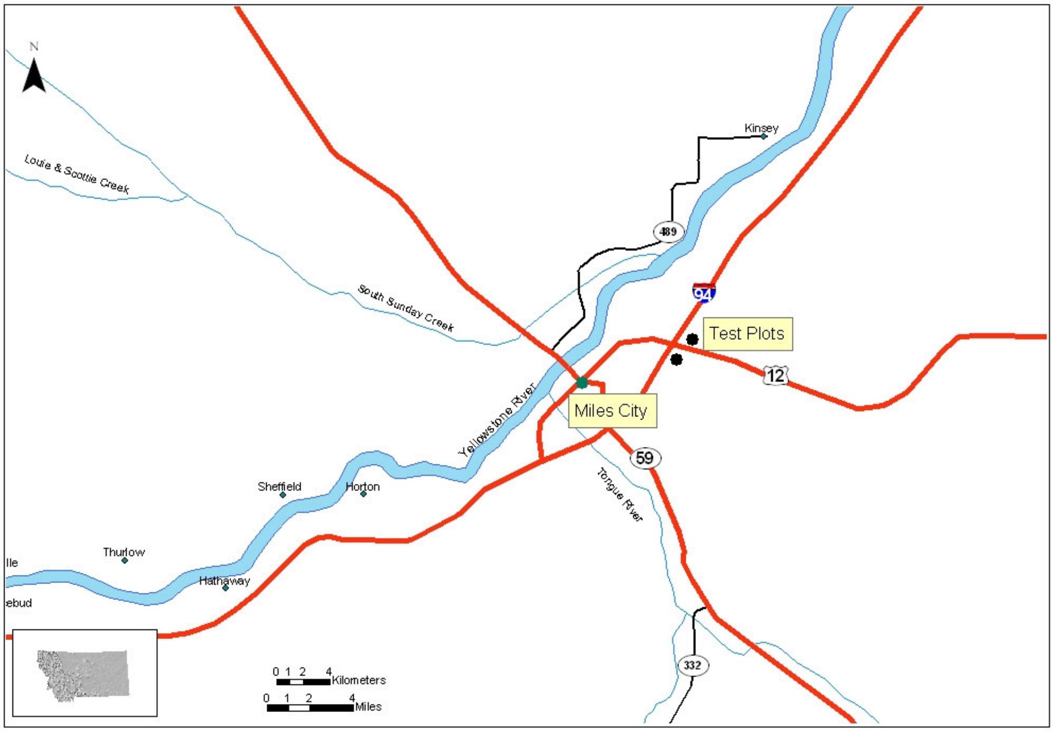


Figure 11. Miles City research area location.

2.2.1 Physiographic Conditions

The two Miles City sites are located on typical Fort Union Formation terrain characterized by rolling to dissected hills underlain by shale and sandstone. Elevations range from 707.1 m (2320 feet) at the Yellowstone River, 3 miles (4.8 km) west of the research area, to about 975.4 m (3200 feet) in the Government Hill area about 6 miles (9.6 km) east of the research site. The elevation in the immediate area of the research plots ranges from about 731.5 m (2400 feet) at the base of the eastbound I-94 exit ramp to 755.9 m (2480 feet) near the top of the east most research plots (11 through 15). All drainage from the research area flows directly to the Yellowstone River via several small un-named ephemeral drainages.

The only geologic unit exposed in the vicinity of the research plots area is the Tullock Member of the Fort Union Formation. A description of this generally flat lying unit states: *Light-yellow and light-brown, planar-bedded, very fine- to medium-grained sandstone interbedded with less dominant gray shale and mudstone, locally, with brownish gray well-indurated argillaceous limestone beds that may contain plant fragment molds. Locally lower part contains narrow, sinuous, steep-walled channel deposits less than 50 ft wide composed of brownish yellow, cross-bedded sandstone. Thickness of member 150 ft. (Vuke et al., 2001)*

Research plots 11 through 15 are located on a cut slope dominated by the gray shale noted above, with occasional indurated thin sandstone lenses that produced a few large (50 cm; 20 inch) angular boulders on the plots. A thin veneer of topsoil had been applied to a portion of the cut and was observed on plots 11 through 15 following tillage. This observation resulted in the additional construction of plots 16 through 20, as detailed below, on a fill slope composed of raw shale.

Research plots 16 through 20 are located on fill material taken from the cut slope where plots 11 through 15 are located. A thin, discontinuous surface layer of coarse wood chips had been applied to this area, apparently with little benefit towards establishment of vegetation. The chips exhibited little, if any, decomposition 10 years following application. The surface of this area is dominated by shale fragments with little weathering evident.

2.2.2 Climatic Conditions

Climatic data is available from two stations near the research sites: 1) Miles City (Station 245685), and 2) Miles City FAA Airport (Station 245690). These stations are approximately 5.4 (8.7 km) and 4 miles (6.3 km) southwest of the research sites, respectively (Figure 11). Elevations at these stations (719.3 [0.45 miles] and 799.8 m [0.5 miles], respectively) bracket the elevation of the research plots. The period of record for Station 245685 is January 1, 1893 through July 31, 1982. The record for Station 245690 extends from January 16, 1937 through the present. The overall amount and distribution of average monthly precipitation at the two stations is very similar, with the airport receiving slightly more total annual precipitation (34.2 versus 33.3 cm; 13.5 versus 13.1 inch) likely due to the 80.5 m (264 feet) elevation difference between the stations (Figure 12). The annual distribution of precipitation is typical of Eastern Montana. Approximately 75 percent of the precipitation occurs during the growing season from April through September with the month of June receiving the greatest amount.

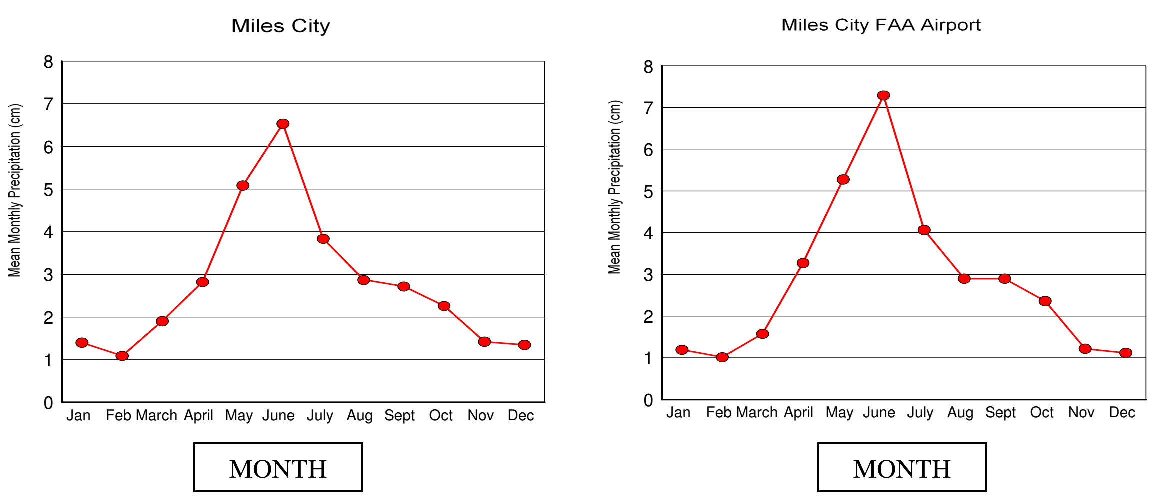


Figure 12. Monthly precipitation for NOAA stations 245685 (Miles City) and 245690 (Miles City FAA Airport).

The October through March period is typically dry and in stark contrast to the Happys Inn sites which receive most of the annual precipitation during this period. Most precipitation in the November through April period occurs as snowfall with the 15 cm (6 inch) maximum accumulated snow depth occurring in February.

The mean annual temperature at the two NOAA sites is 7.7 degrees C (45.9 degrees F). Average maximum temperatures range from -2.7 degrees C (27.1 degrees F) in January to 31.8 degrees C (89.3 degrees F) in July. Average minimum temperatures remain less than 0° C in the November through March period (Figure 13).

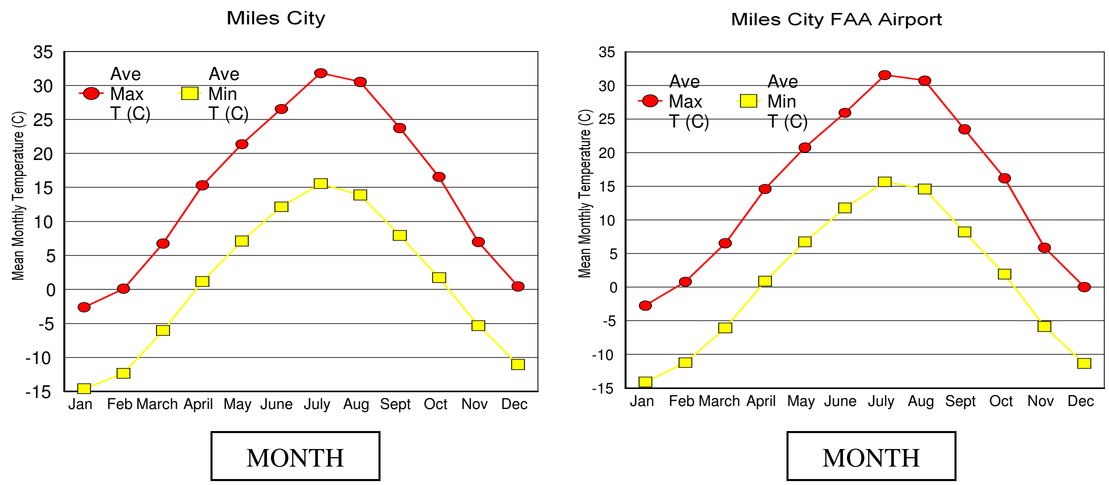


Figure 13. Mean monthly maximum and minimum temperatures for Miles City and Miles City FAA Airport climate stations.

The MAPS program (Caprio et al., 2001) calculated annual potential evapotranspiration (PET) is 79 cm (31 inches). The April through September potential evapotranspiration (PET) of 74.9 cm (29.5 inch) (solar unit method) exceeds precipitation during this period (24.8 cm; 9.7 onch) by nearly 300 percent. The month of July exhibits the greatest PET (20 cm; 7.8 inch) indicating a potential deficit of nearly 16 cm (6.3 inch) between available precipitation and PET (Figure 14). While the bulk of the annual precipitation occurs during the early growing season, available soil moisture is clearly the primary controlling factor for vegetation production at this site.

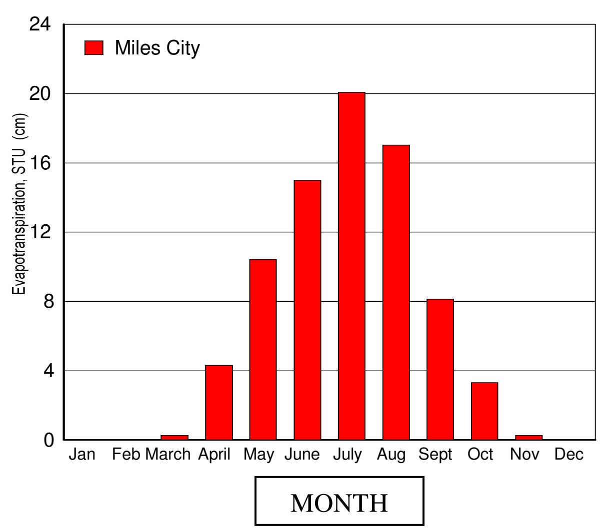


Figure 14. Mean monthly potential evapotranspiration for the Miles City research area. Values determined through MAPS program by Caprio (1971) solar-thermal unit method.

Cool season grasses are adapted to the precipitation patterns observed in the Northern Rocky Mountains and Great Plains and green up early in the spring upon thawing of frozen ground and accumulated winter snowfall. Cool season grasses were seeded at the research sites to mirror species composition on adjacent undisturbed areas and to utilize available soil moisture.

2.2.3 Experimental Design

Ten research plots were established at the Miles City research area (Figure 15). The original study plan included only one site to be comprised of five plots. Two factors encountered during construction of the Miles City plots resulted in a notably modified experimental design. These included:

- After tillage was initiated on the cut slope where plots 11 through 15 were located, it was apparent that some coversoil had been placed on this cut slope;
- Vendor equipment breakdown prevented delivery of the entire required compost volume requiring acquisition of additional compost from a second vendor.

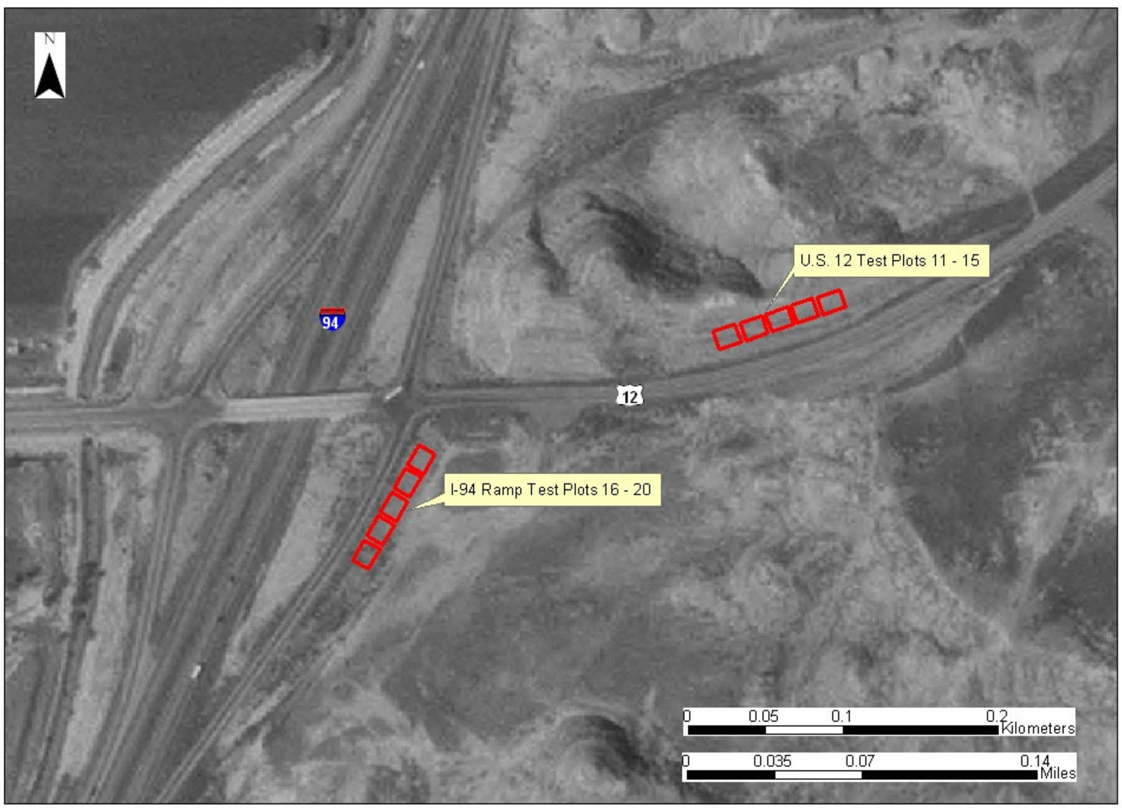


Figure 15. Miles City research plot locations. *(Interchange of US 12 with Interstate I-94 approximately 2 miles east of Miles City).*

The coversoiled cut slope generally exhibited poor vegetation cover and was a suitable test site for the compost application. It did not however, provide a good test for application of compost on raw geologic materials comprised of marine shale. The I-94 off ramp fill was composed of raw shale with essentially no vegetative cover and provided an opportunity for construction of a second set of plots. The resulting plot sizes were reduced to fit the volume of compost ordered which resulted in 186 m^2 (2000 ft^2) plot sizes that were nearly identical to those constructed at Happys Inn.

The vendor loading equipment problems resulted in delivery of only 45.9 m^3 (60 cy) of Earth Systems compost rather than the 58.9 m^3 (77 cy) ordered, with delivery at 11:00 pm the night before application was to begin. There was insufficient time for shipping an additional load of Earth Systems compost. Arrangements were made for the blower truck to load the additional 13 m^3 (17 cy) at Rocky Mountain Compost in Billings, Montana. To maintain the integrity of the experimental design, plots 16 through 20, located on the off-ramp shale fill, were split vertically with Rocky Mountain compost applied to the southwest side and Earth Systems compost applied to the northeast side (Figure 16). Even with the acquisition of the 13 m^3 (17 cy), compost application was short on plot 12, the last plot constructed. This plot was divided vertically with only the west half receiving compost. The experimental design was identical to plots constructed at the Happys Inn sites and included four treatments and a control at each site (Table 7). Following soil sample collection, all plots were contour tilled across the slope.

Figure 16. Plots 19 (compost blanket) and 20 (incorporated compost), I-94 off-ramp area, showing Rocky Mountain compost on the left (light-colored) and Earth Systems compost on the right (dark-colored).

Table 7. Plot treatments for the Miles City research sites.

Site	Plot Number	Treatment	Mean Overall Gradient (%)	Mean Slope Length (m)
Miles City Cut Slope Shale Dominated Material with approximately 5 cm loam/sandy loam soil	11	2.54 cm compost, incorporated with chisel tipped tiller	30.5	12.2
	12	5.08 cm compost, incorporated with chisel tipped tiller (no compost on east ½ plot)	32.0	12.2
	13	5.08 cm compost blanket	33.5	12.2
	14	Control, no compost, chisel plowed	33.5	12.2
	15	2.54 cm compost blanket	33.5	12.2
Miles City Fill Slope Shale Fragment Fill	16	5.08 cm compost, incorporated with chisel tipped tiller	30	15.2
	17	2.54 cm compost blanket	33.5	15.2
	18	Control, no compost, chisel tipped tiller	36.5	15.2
	19	5.08 cm compost blanket	37.5	15.2
	20	2.54 cm compost, incorporated with chisel plow	39.5	15.2

2.2.4 Research Plot Construction

2.2.4.1 Plots 11 through 15, U.S. 12

The experimental design for the Miles City research site delineated a total of 5 plots to be located on the south aspect cut slope immediately east of the eastbound off ramp from Interstate Highway 94 at Mile Post 141 (Figure 15). Plot construction was initiated on April 27, 2004. Plots 11 through 15 were located and staked using a 15.2 m (50 ft) by 22.9 m (75 ft) plot size (Figure 17). The centers of each plot were located and composite soil samples collected.

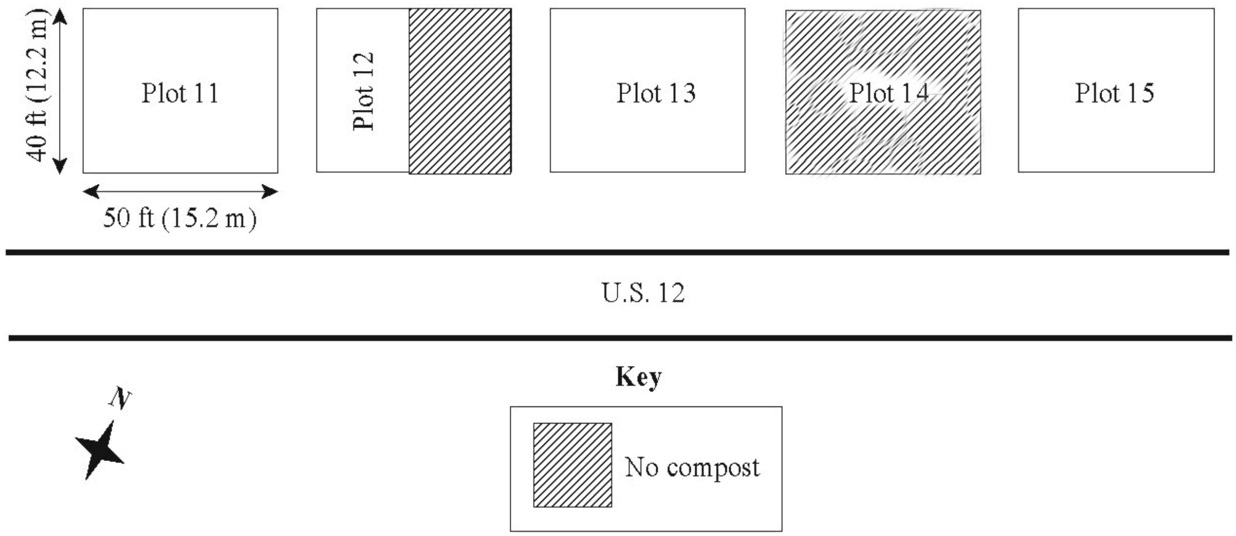


Figure 17. Research plot layouts at the U.S. Highway 12 cut slope site.

Compost was applied to the treatment plots on April 28, 2004 following adjustment of the plot boundaries to accommodate a second set of plots. The plots were downsized by moving the top and bottom boundaries equal distance, thus maintaining the sample location at the center of each plot. Plot width remained 15.2 m (50 ft), with a 3.0 m (10 ft) buffer area between plots and a final constructed slope length of 12.2 m (40 ft). As previously noted, there was insufficient compost volume to completely cover Plot 12 to the desired 5.08 cm (2 inch) thickness.

Only the west half of this plot received compost. Soils on plots 11 through 15 were fine to medium textural class with low coarse fragment content (Table 8). A silt fence was installed the entire length of the site (88.4 m; 290 feet) up-slope from the top of the plots to control run-on sedimentation from areas above the research plots.

Table 8. Highway 12 cut slope preconstruction physical site characteristics.

Plot	Treatment	Mean Overall Gradient (%)	Rock Content > 2mm (%, mass basis)[1]	USDA Textural Class[2]
11	2.54 cm compost, incorporated	30.5	0.93	clay loam
12	5.08 cm compost, incorporated (compost on west half only)	32.0	4.04	clay loam
13	5.08 cm compost blanket	33.5	1.98	Loam
14	Control, no compost	33.5	1.45	Loam
15	2.54 cm compost blanket	33.5	0.92	Loam

[1] ASTM (2002) D422-63
[2] ASA/SSSA, 1986: Method 15-5 Modified Day Hydrometer Method

2.2.4.2 Plots 16 through 20, I-94 Ramp

Research plots 16 through 20 were 12.2 m (40 ft) wide with a slope length of 15.2 m (50 ft) (Figure 18). Plots were separated with 3.0 m (10 ft) buffer strips. All plot areas are 185.8 m^2 (2000 ft^2). This site was characterized by fine textural class soils and high coarse fragment content (Table 9). Nearly all of the coarse fragment content consisted of un-weathered shale bedrock fragments. Each of plots 16 through 20 were split into 2 subplots, with Rocky Mountain compost applied to the south west subplot portion and Earth Systems compost applied to the northeast subplot portion.

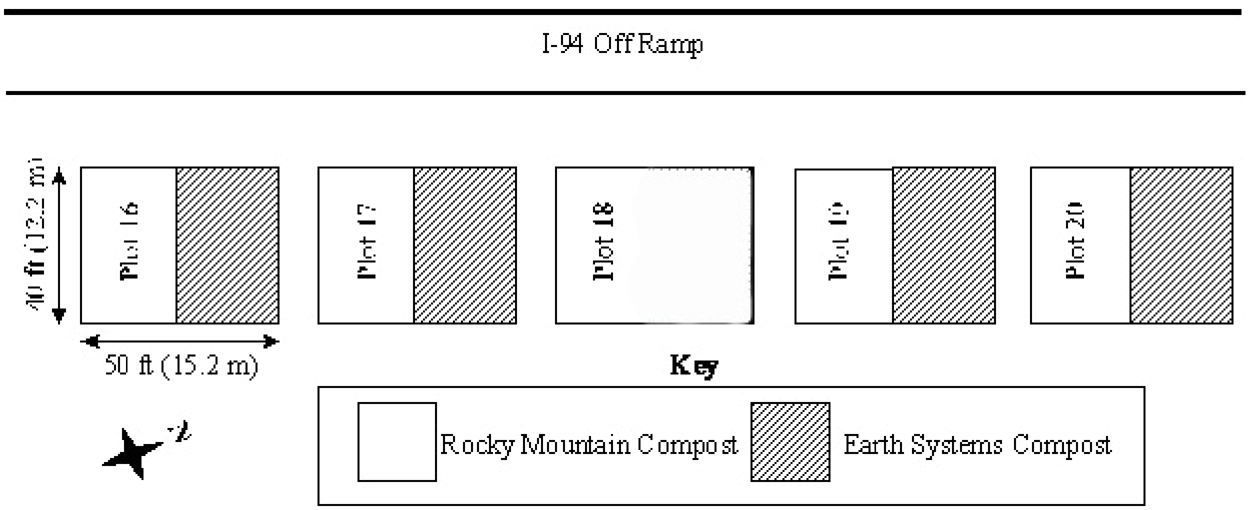


Figure 18. Research plot layouts at the I-94 fill slope site.

Table 9. I-94 fill slope preconstruction physical site characteristics.

Plot	Treatment	Mean Overall Gradient (%)	Rock Content > 2mm (%, mass basis)[1]	USDA Textural Class[2]
16	5.08 cm compost, incorporated	30	17.45	Clay
17	2.54 cm compost blanket	33.5	44.06	Silty clay
18	Control, no compost	36.5	16.48	Clay loam
19	5.08 cm compost blanket	37.5	27.03	Clay loam
20	2.54 cm compost, incorporated	39.5	64.65	Clay

[1] ASTM (2002) D422-63
[2] ASA/SSSA, 1986: Method 15-5 Modified Day Hydrometer Method

2.2.4.3 Seeding

All plots at both Miles City sites were seeded with the same seed mix (Table 10) that was obtained from Bruce Seed Farm, Inc. located near Townsend, Montana. Seed was applied using a hand operated broadcast seeder at a total rate of 1.81 kg (4 lbs) per plot. This rate is the approximate equivalent of 97 kg/ha (86 lbs/ac). Seeding methodology was identical to that used at the previously constructed Happys Inn sites:

> *The seed was applied in two applications, the first on bare substrate and the second following application of 1.3 cm (1 inch) of compost over the first seed application. The remaining compost was applied over the second seed application.*

The seeding scenario acknowledges the fact that a portion of the applied seed will be placed deeper than desired and therefore this portion may have poor emergence. No noxious or restricted weed seed was found in the seed mix. Since no compost was applied to the control plot, seed was applied by a hand broadcast seeder directly to the mineral soil following tillage.

Table 10. Seed mix species used at the Miles City research sites.

Common Name	**Variety**	**Species**	**Percent of Mix (*pure live seed* basis)**
Slender wheatgrass	Pryor	*Elymus trachycaulus* ssp. *trachycaulus*	12.31
Hybrid wheatgrass	Newhy R/S	*Elymus hoffmanii*	18.10
Western wheatgrass	Rosana	*Pascopyrum smithii*	18.77
Beardless wildrye	Shoshone	*Leymus triticoides*	17.92
Alkali sacaton	V.N.S.	*Sporobolus airoides*	6.43
Rocky Mountain bee plant	V.N.S.	*Cleome serrulata*	12.07
Cicer milkvetch	Lutana	*Astragalus cicer*	6.64
Rubber rabbitbrush		*Ericameria nauseous* ssp. *nauseosa*	2.50
Black Greasewood		*Sarcobatus vermiculatus*	2.50

2.2.4.4 Compost Mixing

Compost was mixed into the appropriate test plots using an AEBI tractor pulling a chisel plow. The AEBI tractor is specifically designed for operation on steep slopes. Tillage activity occurred both on the contour and down the slope, well within the rated capabilities of the AEBI tractor. Two incorporation passes were made to mix the compost into the upper 10 cm (4 inches) of the soil. An initial tillage pass was made pulling the plow downslope followed by a final tillage pass on the contour. A total of 2 tillage passes occurred at right angles to one another. The final tillage pass on the contour imprinted the slope with furrows as technique for retarding storm water runoff.

A preliminary evaluation of the effectiveness of the methods used to incorporate compost suggests that while incorporation was relatively good, mixing was not as thorough at the Miles City sites as it was at the Happys Inn sites. The compost mixing with the AEBI TT88 tractor/Ford tiller implement combination was not as complete as that achieved using the LMC snowcat at the Happys Inn sites probably due to the considerable additional mixing achieved by the snowcat grousers, but it was deemed adequate to sufficiently incorporate the compost to minimize erosion of the material from both wind and water. Both compost and soil were clearly discernable following the two tillage passes at 90 degrees.

3.0 MATERIALS AND METHODS

Soil samples were collected from all plots prior to construction and after 2 years of plant growth. In addition, samples of the stockpiled compost were collected prior to application. Vegetation and erosion were monitored twice each year for a 3-year period to chart the treatment effect on vegetation development and erosional stability.

3.1 Soil Sampling

A single composite soil sample was collected from each plot. All samples were collected using identical methodology. The center of each plot was located and from this point, three subsample sites were located at 120 degree intervals on a 3 m (9.8 ft) radius, with one leg directly down-slope. All samples were collected by trenching the soil pit wall to a depth of 10.2 cm (4 inch). Each sample consisted of a 3.8 liter (1 gallon) zip lock bag. The primary intent of the two composite samples was to provide sufficient sample volume for all analyses, but it also provided necessary quality control/quality assurance samples. Samples were analyzed for numerous parameters including pH, specific conductance (SC), sodium adsorption ratio (SAR), N, P and K, organic matter (OM), C:N ratio, coarse fragment content and soil textural class (Table 11) and Appendix A.

Table 11. Soil sample analyses and methods.

Analysis	Method
Saturated Paste Extract pH	ASA/SSSA[1], 1982: Methods 10-2.3, 10-3.2
Saturated Paste Extract SC	ASA/SSSA, 1982: Methods 10-2.3, 10-3.3
SAR	ASA/SSSA, 1982: Methods 10-2.3, 10-3.4 (cations analyzed by Atomic Absorption Spectrometer-AAS)
NO_3-N	ASA/SSSA, 1982: Methods 33-8.2, 33-8.3
Olsen P	ASA/SSSA, 1982: Method 24-5.4
K	ASA/SSSA, 1982: Method 9-3.1, modified (extract diluted in 0.5 % La_2O_3 with1% HCl & analyzed AAS)
OM	ASA/SSSA, 1982: Method 29-3.5.2, Modified Walkley-Black
Coarse Fragment Content	ASTM D422-63
Textural Class	ASA/SSSA, 1986[2]: Method 15-5 Modified Day Hydrometer Method

[1] ASA, 1982.
[2] ASA, 1986.

Composite soil samples were collected from each research plot. Soils samples were first collected at the Happys Inn sites in Fall of 2003 and at Miles City in Spring 2004, immediately following plot staking and prior to compost addition. Composite soils samples were also collected at each research site in the Fall of 2005, which was the end of the second growing season at both Happys Inn and Miles City plots. The soil samples provide data characterizing the pre- and post-treatment conditions. Soil samples were collected from the top 10 cm (4 inches) of the soil.

Analyses of each composite soil sample included: pH, electrical conductivity, sodium adsorption ratio (SAR), N/P/K, organic matter, C:N ratio, rock content and soil textural class (Table 11). These data establish the pretreatment soil condition and a point of comparison following two years of plant growth.

3.2 Compost Sampling

3.2.1 Happys Inn Research Site

Compost for the Happys Inn sites was obtained from EKO Compost in Missoula, Montana. Two composite samples were collected from the compost stockpile located at the MDT's Crystal Creek maintenance facility. Each sample consisted of approximately 20 subsamples taken from all portions of the stockpile. Subsample sites were different for each composite sample. Sample analyses are shown in Table 12.

Table 12. Analytical methods for determination of compost physical and chemical characteristics.

Analysis	Method
Sample Preparation	Test Methods for the Examination of Composting and Compost[1] (TMECC) method 02.02
Total Solids and Moisture	TMECC method 03.09, ASA/SSSA 21-2.2 (1986)
pH	TMECC method 04.11
Electrical Conductivity	TMECC method 04.10
N	TMECC method 04.02
C	TMECC method 04.01-A

[1] U.S. Department of Agriculture and the United States Composting Council, 2001.

3.2.2 Miles City Research Site

Compost for this project was obtained from two sources: Earth Systems near Amsterdam, Montana, and Rocky Mountain Compost in Billings, Montana. Two composite samples were collected from each of the two types of compost. Sample analyses are shown in Table 12.

3.3 Vegetation Monitoring

Vegetation monitoring occurred in Spring and Fall of 2004, 2005 and 2006. Response variables assessed for vegetation performance for each treatment plot are as follows:

Year 1 (2004)

- Happys Inn: Seedling establishment, seedling density and percent canopy cover;
- Miles City: Seedling establishment and seedling density;

Year 2 (2005)

- Happys Inn: Percent canopy cover (Spring and Fall), above ground production (Fall only);
- Miles City: Percent canopy cover (Spring and Fall), no production was collected due to drought conditions;

Year 3 (2006)

- Happys Inn: Percent canopy cover (Spring and Fall);
- Miles City: Percent canopy cover (Spring and Fall), above ground production (Mid-summer).

Plant canopy cover was measured by morphological class, which included perennial grass, annual grass, forb, weedy forb and shrub. Canopy cover was determined using a 20 x 50 cm (7.9 x 19.7 in) frame (Daubenmire, 1968) at 10 predetermined transect stations within each treatment plot. Transects were permanently located within each plot during the Spring of 2004. Production was collected by clipping all above ground vegetation in five 20 x 50 centimeter frames located along the same transects as the cover measurements. The frame used for production collection was located on the opposite side of the transect from the cover frames. Clipped vegetation was separated by morphological class (same classes as cover), transported back to the Reclamation Research Unit Laboratory, dried and weighed. Vegetation results are reported in Appendix B.

3.4 Erosion Monitoring

Erosion on all plots was qualitatively evaluated during each site visit. The Erosion Condition Classification, Montana Revised Method (Clark, 1980) was used for the erosion evaluation. Estimates of volume of eroded material deposited below treatment plots were noted, but no quantitative attempt was made to calculate actual sediment yields from treatment plots. Erosion results are reported in Appendix C.

4.0 RESULTS

Results from this investigation are grouped into equipment performance, vegetation performance and erosion control. Each aspect contributes significantly to MDT's ability to implement compost-based soil treatments and the resulting affect imparted to vegetation establishment, growth and persistence.

4.1 Equipment Performance

4.1.1 Happys Inn

The equipment utilized for this study was limited. It included:

- Express Blower (Rexius) blower truck model EB-30;
- LMC model 3700C snowcat using Pisten Bully 2.5 m (8.2 ft) wide steel tracks and a standard agricultural 3-point quick attach hitch; and
- A 2.5 m (8.2 ft) wide 3-point mounted, spring-shanked Graham Hoeme chisel plow.

The performance of this equipment, along with one demonstration unit (Land Tamer) is discussed in the following subsections.

4.1.1.1 Blower Truck

The blower truck experienced no difficulties applying compost to the research plots (Figure 19). The maximum length of the research plots was only 10 to 20 percent of the capability of the truck (standard hose length is 111.6 m or 366 feet) and no clogging of feeders or blower hose occurred. Minor hand shoveling inside the truck box was required to feed compost to the walking floor when the unit was near empty. This was apparently caused by the tilt of the unit produced by stationing it partially in the borrow pit to maintain a clear traffic lane. Compost application was timed for several plots. Approximately 10 minutes was required to apply a controlled 1.3 cm (1 inch) compost layer on each plot and an additional 15 to 20 minutes to apply the remaining 3.8 cm (1.5 inch) of compost on the 5.1 cm (2 inch) treatments for an approximate rate of 0.05 ha/hr (0.02 acre/hr) (Table 13). These rates should not be construed as the expected rate on a full scale project. Due to the size of the research plots, more time was required to ensure the applied compost was within plot boundaries. The application of two specific compost layers increased application time by about 10 percent. Manufacturer literature suggests normal application rates of 0.76 to 1.53 m^3 (1 to 2 cubic yards) per hour. At the higher rate, a 5.08 cm (2 inch) compost blanket would be applied at 0.18 ha/hr (0.07 acre/hr).

Figure 19. Express Blower Model EB-30 applying compost at the MP 77 site.

Table 13. Rate of compost application observed during plot construction.

Plot Number	Plot Area (m^2)	Applied Thickness (cm)	Application Time (min:sec)
2	212	1.3	9:00
2	212	3.8	19:00
4	242	1.3	11:00
5	193	1.3	15:30
10	232	1.3	10:30
10	232	3.8	15:20

4.1.1.2 Snowcat

The snowcat utilized for this project was a modified LMC 3700C (Figure 20). This unit is powered by a Caterpillar 3208 diesel engine rated at 165 kw (225 hp) and weighs approximately 8160 kg (18,000 lbs). Modifications to this unit were:

- Reinforced undercarriage;
- Upgraded cooling system;
- Pisten Bully drive sprockets and 2.5 m wide steel tracks;
- Rear 3-point quick hitch;
- Front 3-point brackets to mount broadcast seeder; and
- MSHA certified ROPS canopy.

Figure 20. Modified LMC 3700C initiating tillage on plot 8, MP 69 site.

The snowcat had more than sufficient power to use the chisel plow while traversing upslope at both research sites. The performance of the unit was excellent on the fine textured materials at MP 77. Traction was very good in the silt dominated material at this site and the operator had very good control of induced track slippage (for additional tillage/mixing action) and very good maneuverability. Operation was equally good while traversing up-down or across slope at this site.

The performance of the unit at the MP 69 site was compromised by the numerous boulders and large cobbles. While the snowcat had sufficient power and traction overall, the rigid suspension resulted in traction loss when riding up on boulders with a resulting excess of track slippage. In addition to undesirable effects on compost incorporation (moved an excessive amount of compost down-slope), it made steering control more difficult. An effort to traverse across the slope at MP 69 resulted in a broken track. This was likely the result of both the weight of the machine applying excessive pressure on the downhill track boggy wheel guides and the gravel/cobble material that accumulated in the track.

The snowcat 3-point hitch arrangement performed very well in all situations except when breaking over the top of the cut slope onto native slope. This radical attitude transition exceeded the travel limit of the 3-point hitch and tended to pull the implement out of the soil. This situation should be expected with any type of 3-point mounted equipment. As noted previously, this would likely be a minor problem on a full-scale project. The 3-point system allowed the implement to be raised at any time, therein enhancing maneuverability and expediting production by allowing uninhibited backing on short slopes.

4.1.1.3 Chisel Plow

The Graham Hoeme chisel plow utilized for this study worked equally well in both coarse and fine textural classes of material (Figure 21). Shank spacing was set at 0.35 m (1.1 ft) for the 2.4 m (8 ft) wide implement. Potential tilling depth was well in excess of the specified 10.2 cm (4 in) compost incorporation depth for this project. No breakage or other problems were encountered with this unit. It is likely that a wider implement of similar design could have been utilized, especially at the MP 77 site.

Figure 21. Graham Hoeme 2.4 m (8 ft) spring-shanked chisel plow at the Loon Lake site.

4.1.1.4 Land Tamer

PFM Manufacturing provided a standard industrial LT model for demonstration purposes at the MP 69 site (Figure 22). This unit is a diesel powered eight-wheeled vehicle utilizing a hydrostatic drive. While this machine had no trouble traversing the 50 percent slopes at MP 69, either on the contour or at an angle, it suffered from problems similar to the snowcat. Its rigid suspension limited wheel contact when riding over large cobble and boulders. The resulting loss of traction was sufficient to prevent direct traverse up slope at this site even without any tillage implements. The Land Tamer was not demonstrated at the MP 77 site. It is the authors' opinion that this unit would have performed acceptably well on the silt-dominated materials using a small tillage implement.

Figure 22. Land Tamer industrial model LT adjacent to Loon Lake research site.

4.1.2 Miles City Equipment Evaluation

The equipment utilized for this study included:

- Express Blower (Rexius) blower truck model EB-30;
- AEBI Terratrac model TT88 with optional category 1/2 standard agricultural 3-point hitches (front and back); and
- A Ford 3 m wide 3-point mounted, spring-shanked tiller with nine chisel points.

The performance of this equipment is discussed in the following subsections.

4.1.2.1 Blower Truck

The blower truck utilized for the Miles City plot construction was the same unit used for the Happys Inn sites (Figure 23). No problems were encountered using two additional compost sources that exhibited two very different moisture contents. Production rates were similar to that chronicled at the Happys Inn sites.

Figure 23. Express Blower (Rexius) blower truck model EB-30 applying Earth Systems compost to Plot 17.

4.1.2.2 AEBI Terratrac TT88 Steep Terrain Tractor

The tractor employed for this work was an older (1990) AEBI Terratrac model TT88 equipped with a hydrostatic drive (Figure 24). This unit was rented from the Bridger Bowl Ski Area near Bozeman, Montana where its main use is mowing ski runs. The Phase I report for this research project identified the AEBI tractors as good candidates for compost incorporation on steep cut slopes. The Phase I report (Jennings et al., 2003) contains a listing of all current and past AEBI Terratrac models produced. The TT88 used shares the dual 3-point system and dual PTOs (front and back) common to most Terratrac models, had a EROPs type enclosed cab, and a 44 kW (60 hp) diesel engine. While the slope steepness of the Miles City research plots fell somewhat short of the desired 50 percent, the abilities of the TT88 were not seriously challenged working on these plots (30 to 40 percent range). Tillage both across and up-down slopes was completed easily.

Figure 24. AEBI Terratrac TT88 tilling on the contour along U.S. Highway 12.

Following adjustment of tire pressures to meet that recommended by AEBI, engagement of the differential locks was unnecessary. There was little problem turning at will on-slope. While this unit performed very well at the Miles City sites, it would likely have had difficulties at the Mile Post 69 site near Happys Inn that was composed of loose cobble, boulders and gravel. The only difficulty noted during construction of the Miles City plots was controlling the tillage implement till depth when working across the slope and encountering small gullies. When these features were traversed, the tractor would nose down when entering, which tended to pull the 3-point mounted cultivator out of the ground, and when exiting the gully the cultivator tended to be pushed down. These operating characteristics would be similar to any 3-point systems and it was controllable by constantly monitoring the tillage depth when crossing these features. The 3-point system allowed complete maneuverability on slope. Tillage speeds of several km/hr were obtainable both across and up-down slopes.

4.1.2.3 Ford Spring-Shanked Tiller

The Ford tiller used for this work had 9 shanks mounted at 0.30 m (1 foot) centers (Figure 25). All shanks were spring-loaded which allowed passage over several large boulders encountered when tilling plots 11 through 15. All shanks were equipped with chisel points. All initial plot tillage was across the slope. Compost mixing was initially up-down the slope followed by a second pass across the slope. The AEBI TT88 had little difficulty obtaining the desired 10.2 cm (4 inch) tillage depth and was capable sinking the shanks 0.3 m (1 foot), especially when tilling down slope.

Figure 25. Ford spring-shanked tiller on Plot 20 (Rocky Mountain compost in foreground, Earth Systems material in background).

4.3 Soil Chemistry

Soil samples collected from the Happys Inn and Miles City research sites in 2003, 2004 and 2005 were submitted for laboratory analysis. Results from the analytical laboratory are exhibited in Tables 14, 15 and 16. Soil samples were collected prior to plot construction from each plot to establish the chemical characteristics prior to treatment. The same plots were sampled at the end of the second growing season. Soil samples collected two years after compost addition showed the effect of compost addition to the treated plots either when compost was applied as a blanket or incorporated into the soil. Inferences between individual plots are not backed up with statistical comparisons derived from plot replication and quantification of variance. Multi-part composite sampling was employed to achieve representative samples. The pre-treatment plots at Happys Inn exhibited low levels of fertility and organic matter. The Middle Thompson Lake plots additionally revealed an elevated signature of sodium in the soil solution and resulted in modestly elevated SAR levels (4.6-24.5). After compost treatment the SAR was markedly reduced in the treated plots (0.4-2.9) while the control plot (1) was essentially unchanged (SAR 10.6). Soil fertility measured as N-P-K was notably improved on the compost treated plots. Organic matter levels at the Middle Thompson Lake sites averaged 7.4% on the compost treated plots compared to 0.2% in the control plot. Similarly, organic matter levels measured in treated plots from the Loon Lake site approached 8% while the control plot contained 0.72% OM. Available NO_3-N levels in the treated plots were similar to the controls at Happys Inn while P and K levels remained elevated compared to the control 2 years after treatment. Detailed analytical results are presented in Appendix A.

Table 14. Soil analytical results for the Middle Thompson Lake Site comprised of glacial silt parent material, before and after treatment.

Happys Inn Middle Thompson Lake – 2003 Prior to Treatment

Sample ID*	pH	EC(uS)	SAR	OM (%)	NO_3-N mg/kg	P mg/kg	K mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg
Plot-1	8.7	1000	11.1	0.24	0.5	3.3	66	11	209	8
Plot-2	8.6	1970	24.5	0.14	2.1	2.2	62	13	455	5
Plot-3	8.2	1560	6.3	0.31	1	5	60	38	251	58
Plot-4	8.3	2090	9.8	0.09	0.4	1.4	68	58	391	26
Plot-5	8.4	1160	4.6	0.06	0.3	1.7	50	48	163	14

Happys Inn Middle Thompson Lake – 2005 After Treatment

Sample ID	pH	EC(uS)	SAR	OM	NO_3-N mg/kg	P mg/kg	K mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg
Plot-1	8.45	880	10.6	0.16	0.7	3.7	68	7.5	176	8.7
Plot-2	7.86	1021	2.9	2.62	1.0	81.2	162	46.1	118	51.6
Plot-3	7.29	1654	0.5	5.31	1.4	156	310	126	33.7	160
Plot-4	7.19	1277	0.5	10.6	1.7	182	512	81.5	26.9	97.6
Plot-5	7.23	1353	0.4	11.2	2.8	256	544	87.8	21.4	105

* Plot 1=Control, no compost, Plot 2=2.54 cm compost incorporated into soil, Plot 3=5.1 cm compost incorporated into soil, Plot 4=2.54 cm compost blanket, Plot 5= 5.1 cm compost blanket.

Table 15. Soil analytical results for the Loon Lake Site comprised of alluvial rock parent material, before and after treatment.

Happys Inn Loon Lake – 2003 Prior to Treatment

Sample ID*	pH	EC(uS)	SAR	OM	NO_3-N mg/kg	P mg/kg	K mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg
Plot-6	8.1	400	0.2	0.23	4.3	6.1	48	8	6	54
Plot-7	8	580	0.2	0.4	5.9	8.6	52	16	8	83
Plot-8	8.4	650	0.2	2.65	7.3	20.3	134	16	6	110
Plot-9	8.5	560	0.1	0.58	2.7	6.1	68	13	5	93
Plot-10	8.5	540	0.2	0.68	3.1	7.5	46	19	6	72

Happys Inn Loon Lake – 2005 After Treatment

Sample ID	pH	EC(uS)	SAR	OM	NO_3-N mg/kg	P mg/kg	K mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg
Plot-6	7.84	366	0.6	0.72	0.9	8.9	62	7.9	17.1	48.6
Plot-7	7.73	950	0.4	4.52	1.6	73.8	184	40.4	19.6	137
Plot-8	7.79	836	0.3	6.7	1.7	125	196	39.7	13.7	121
Plot-9	7.86	761	0.3	7.55	0.8	103	256	35.3	14.3	92.1
Plot-10	7.51	836	0.3	13.2	3.7	212	442	46.0	16.1	90.4

* Plot 6= Control, no compost, Plot 7=2.54 cm compost incorporated into soil, Plot 8=5.1 cm compost incorporated into soil, Plot 9=2.54 cm compost blanket, Plot 10=5.1 cm compost blanket.

Less clear trends in fertility, organic matter levels and SAR were observed at the Miles City plots (Table 16). The control plots (14 and 18) exhibited OM, N and K levels comparable to the treated plots. Phosphorous levels measured in the compost treated plots were elevated compared to the controls. Several factors may have contributed to the lack of soil fertility differences observed between the treated plots and control. Variability at this site may be partially attributable to the cover soil placed over plots 11-15 and prior wood chip treatment applied to plots 16-20.

Table 16. Soil analytical results for the Miles City Research Sites comprised of marine shale parent material, before and after treatment.

Miles City Site – 2004 Prior to Treatment										
Sample ID*	**pH**	**EC(uS)**	**SAR**	**OM**	**NO_3-N mg/kg**	**P mg/kg**	**K mg/kg**	**Mg mg/kg**	**Na mg/kg**	**Ca mg/kg**
Plot-11 ***U.S. 12***	9	2020	15.5	2.36	16.7	4.4	316	14	474	48
Plot-12 ***U.S. 12***	8.5	5090	26.4	1.9	21.3	3.4	148	49	1410	135
Plot-13 ***U.S. 12***	8.9	1510	13.3	1.72	4.9	5	156	16	428	52
Plot-14 ***U.S. 12***	8.9	1020	8.8	1.83	3.3	3	166	11	224	31
Plot-15 ***U.S. 12***	8.8	870	5.8	1.71	4.6	3.7	180	15	157	31
Plot-16 I-94 Ramp	7.8	10100	29	8.56	163.6	14.3	232	340	3350	452
Plot-17 I-94 Ramp	8.3	6300	28.5	3.45	84.4	12.1	236	94	2170	284
Plot-18 I-94 Ramp	8.6	4820	33.2	2.08	78.5	6.2	202	25	1340	82
Plot-19 I-94 Ramp	8.4	6070	30.6	2.43	62.2	5.3	170	46	1760	175
Plot-20 I-94 Ramp	8.3	4890	31.8	1.82	87.5	4.4	250	28	1350	91
Miles City – 2005 After Treatment										
Sample ID*	**pH**	**EC(uS)**	**SAR**	**OM**	**NO_3-N mg/kg**	**P mg/kg**	**K mg/kg**	**Mg mg/kg**	**Na mg/kg**	**Ca mg/kg**
Plot-11 ***U.S. 12***	8.83	4980	19.7	5.41	42.2	175	1942	40.0	1000	128
Plot-12 ***U.S. 12***	8.77	7090	24.0	4.49	35.8	124	1478	63.0	1470	181
Plot-13 ***U.S. 12***	8.54	3105	7.1	4.40	21.5	114	1852	42.0	341	107
Plot-14 ***U.S. 12***	8.01	9720	15.9	3.37	10.7	8.5	220	267	1760	492
Plot-15 ***U.S. 12***	8.43	1939	4.7	3.52	22.4	83.6	1638	24.3	179	69.6
Plot-16A# I-94 Ramp	8.36	5270	1.7	10.6	20.8	67.8	862	61.0	108	193
Plot-16B## I-94 Ramp	8.71	5610	18.1	11.5	54.5	271	2640	57.0	1070	169
Plot-17A I-94 Ramp	8.97	6800	28.4	7.21	29.0	24.4	636	47.0	1530	141
Plot-17B I-94 Ramp	8.95	6870	27.7	7.4	54.9	169	1426	51.0	1630	178

Table 16 (continued). Soil analytical results for the Miles City Research Sites comprised of marine shale parent material, before and after treatment.

Plot-18A I-94 Ramp	8.66	7330	27.4	3.17	43.6	7.9	272	48.0	1560	167
Plot-18B I-94 Ramp	8.98	5290	35.4	2.02	23.8	5.8	300	16.1	1220	63.1
Plot-19A I-94 Ramp	8.84	4980	25.0	5.53	27.0	36.3	596	27.9	1070	92.3
Plot-19B I-94 Ramp	8.82	4840	24.5	10.8	64.9	254	2540	29.4	1070	96.3
Plot-20A I-94 Ramp	8.84	5370	25.9	4.19	9.0	25.4	506	27.8	1140	101
Plot-20B I-94 Ramp	8.86	5780	28.5	4.56	21.1	101	854	28.7	1350	122

* Plot 11= 2.54 cm compost incorporated into soil, Plot 12=5.1 cm compost incorporated into soil, Plot 13=5.1 cm compost blanket, Plot 14=Control, no compost, Plot 15=2.54 cm compost blanket, Plot 16=5.1 cm compost incorporated into soil, Plot 17=2.54 cm compost blanket, Plot 18= Control, no compost, Plot 19=5.1 cm compost blanket, Plot 20=2.54 cm compost incorporated into soil.
#- The ‘A’ half of the plot was amended with Rocky Mountain Compost.
##- The ‘B’ half of the plot was amended with Earth Systems Compost.

Sodium levels in the pre-treatment soils followed predictable patterns with Eastern Montana marine shale parent materials reporting the highest SAR levels. Addition of compost, tillage and seeding had little effect on SAR at the Miles City test plots which showed persistent high SAR levels two years after plot construction. Plot by plot variation is attributed to spatial variability and a lack of replicated soil sampling. The least sodium observed was in northwest Montana on the alluvial rock parent materials where SAR levels were less than 1 before and after treatment. The most anomalous SAR levels were associated with the glacial silt. The lacustrine glacial silt found at the Middle Thompson Lake sites exhibited SAR levels between 4 and 25 prior to compost treatment. Two years after vegetation establishment the SAR levels were less than 3.0 on all of the treated plots. While no definitive answer is available to explain the drop in SAR, the change may well be related to water balance with salts being leached deeper in the profile during the winter and spring months while growing plants utilize nearly all precipitation during the growing season. The net result is less evaporation from the soil surface due to vegetation cover and a commensurate reduction in salts wicked to the soil surface during the hot summer months.

4.3.1 Compost Evaluation

The chemical characteristics of compost used in Happys Inn and Miles City research plots are exhibited in Table 17.

Happys Inn. Analysis of the EKO Compost used on the 8 compost treated plots near Happys Inn confirmed the product quality. Measured pH, EC, total carbon and total nitrogen levels were all within expected ranges. The low amount of inorganic solids and comparatively high levels of OM corroborate the compost quality.

Table 17. Chemical characteristics of compost used in research plots.

Site Name and Compost Source	pH	EC (dS/m)	Total C (%)	Total N (%)	% H_2O	TKN % N	C:N Ratio	Inorganic Solids %	Organic Matter %
Happys Inn: EKO compost	6.8	1.01	28.0	1.25	31.7	0.82	22.4:1	31.4	36.9
Miles City: Rocky Mountain Compost	9.0	1.24	15.3	0.55	19.7	Not analyzed	27.8:1	54.5	25.8
Earth Systems Compost	9.1	4.31	22.1	1.44	37.7	Not analyzed	15.3:1	39	23.3

Miles City. Compost analyses indicated that notable differences exist between the two types of compost:

- Earth Systems material exhibited notably higher EC (4.31 versus 1.24 dS/m);
- Earth Systems Compost is dairy manure based while the Rocky mountain compost utilizes a livestock bedding mixture of sawdust and horse manure;
- Earth Systems exhibited higher total carbon (22.1 versus 15.3 percent);
- Earth Systems exhibited higher total nitrogen (1.44 versus 0.55 percent); and
- Earth Systems exhibited higher moisture content (37.7 versus 19.7 percent).

The C:N ratio of the Earth Systems material (as calculated from total N by combustion) was 15.3 while the corresponding value for Rocky Mountain Compost was 27.8. The physical appearance of each compost product was also dissimilar. The Earth Systems was dark in color, moist and heavy while the Rocky Mountain Compost was light brown in color, dry and light weight. Wind erosion of both compost materials was observed, especially on the compost blanket plots after prolonged periods of dry weather.

4.4 Vegetation Performance

Pre-treatment vegetation at all of the research sites was very poor with some areas completely void of vegetation. After two growing seasons, desirable perennial grasses were thriving at all of the research sites (Figures 26 and 27). At the same time the adjacent control plots where no compost was applied exhibited very limited vegetation development. At the Happys Inn site (Figure 26) the control plot (not shown in the image) exhibited vegetation cover very similar to the unvegetated strips between the compost treated plots. At Miles City the control plot is visible as the middle plot shown in the 5 plot sequence. Detailed vegetation data are presented in Appendix B.

Figure 26. Happys Inn research plots near Middle Thompson Lake, U.S. Highway 2, Spring 2005.

Figure 27. Miles City research plots constructed on the I-94 off-ramp near the U.S. Highway 12 junction, Spring 2005.

4.4.1 Perennial Grass Cover

Analysis of perennial grass development and persistence is presented in Figure 28 at the Happys Inn glacial silt site. Since the seed mix was dominated by perennial grasses they were used as an overall performance metric for the compost treatments compared to the control. The research sites at Happys Inn were constructed in the fall of 2003 with the expectation that vegetation monitoring during the first growing season would be limited to measurement of emergent plant density. However, by June of the first growing season sufficient vegetation developed that measurement of cover was possible and by September of 2004 many of the seeded species had grown to maturity on the compost treated plots. The remarkable growth of the seeded species during the first growing season can be seen in the photo chronology presented in Appendix D. The progression of plant growth on plot 3, the 5 cm (2 inch) compost rate incorporated into the top 10 cm (4 inch) of soil is shown in Appendix Figure D1. Photographs are not presented for all of the plots; rather plot 3 was selected as a good representation of the compost treatments at the glacial silt research sites. Figure 28 also shows that perennial grass cover peaked in the first growing season and then held at relatively stable levels during the second and third growing season. The control plot exhibited very little perennial grass growth with most plants observed only a few centimeters tall and often withered and stressed in appearance. The response of perennial grasses to applied compost was unmistakable and readily observed from the highway as robust green rectangles.

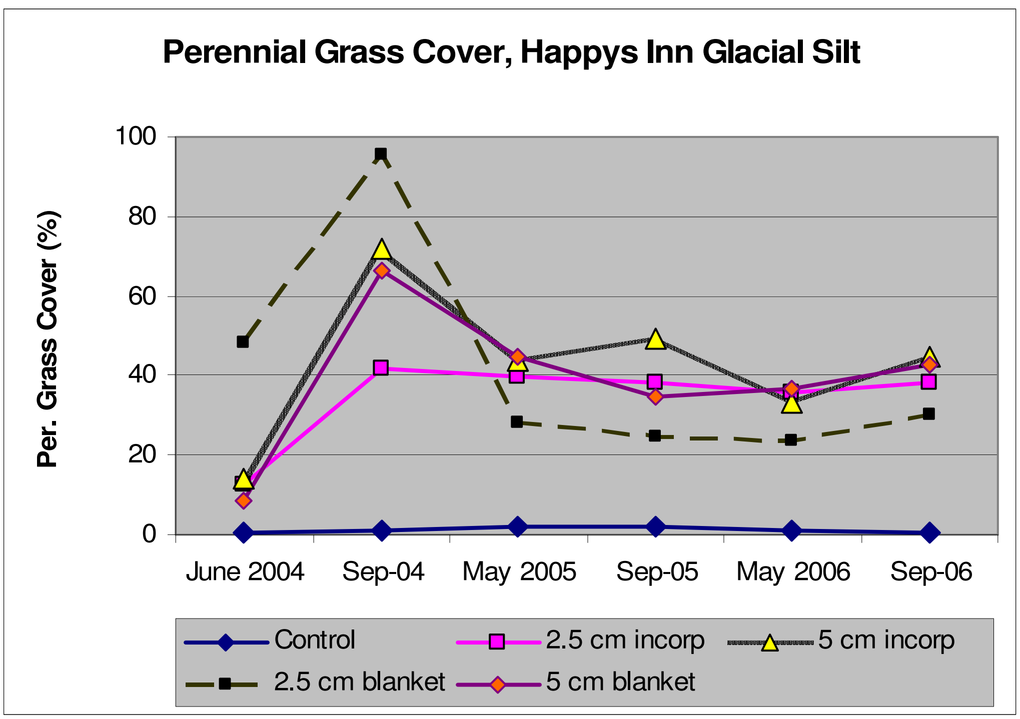


Figure 28. Response of perennial grasses to applied compost treatments compared to an untreated control at the Middle Thompson Lake research sites.

In addition to measuring cover of perennial grasses, the cover of annual grasses, desirable forbs, weedy forbs, rock, compost and bare ground were reported during each monitoring episode. The mean observations of cover are reported in Appendix B-2. A total of 10 cover frames were recorded from each plot along a fixed diagonal transect during each monitoring event. Of particular relevance to the glacial silt site is the abundance of litter (up to 50%) during the final monitoring event (Appendix Table B-2.6). Most of the litter resulted from the prominent vegetation response occurring during the first growing season.

Mean perennial grass cover at the alluvial rock research site near Loon Lake on U.S. Highway 2 showed the affect of compost addition compared to the control (Figure 29). All of the compost treatments exhibited better plant growth than the untreated control. Similar to the sites near Middle Thompson Lake, the Loon Lake research plots exhibited excellent first year vegetation development, but comparatively more stable levels of perennial grass cover during the three years of monitoring. A photo chronology of plot 8, the 5 cm (2 inch) incorporated compost treatment is shown in Appendix Figure D2.

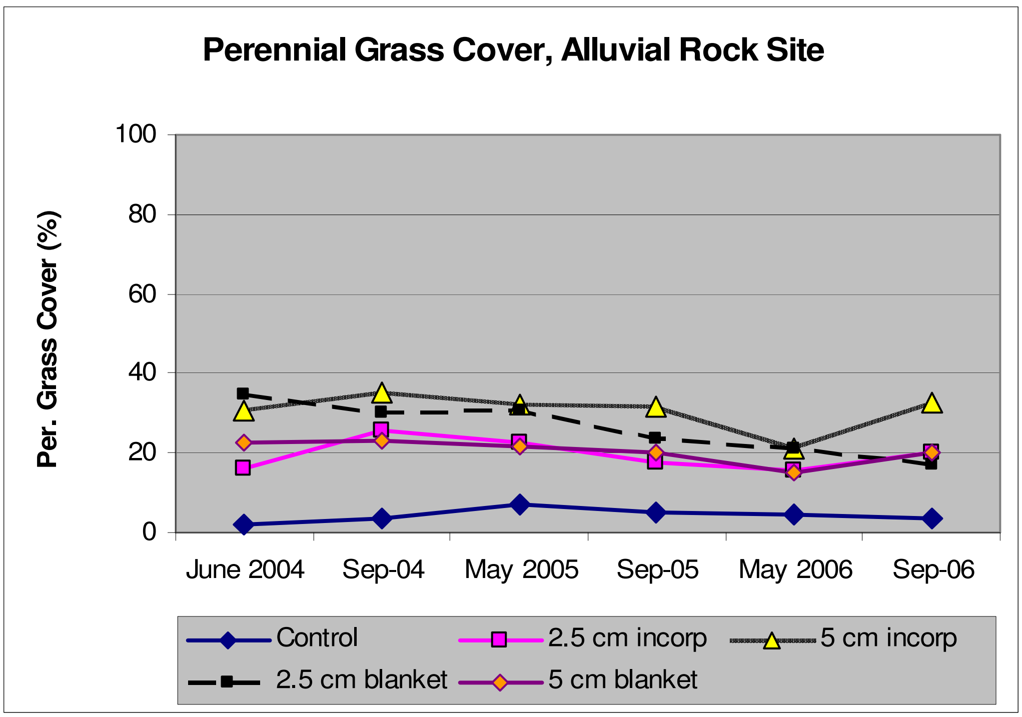


Figure 29. Response of perennial grasses to applied compost treatments compared to control at the Loon Lake research sites.

Vegetation development at the Miles City plots started out very slowly due to drought conditions in the eastern plains of Montana observed during the 2004 growing season. More normal precipitation patterns returned during the 2005 growing season allowing seeded species that had been struggling during the first growing season to become well established. Figure 30 shows the perennial grass cover observed at research plots 11-15 constructed on thin coversoil and shale outcrop parent material. These plots were constructed in May 2004. Initial monitoring occurred in July 2004 recording only the density of emergent plants (Appendix B-2). Vegetation cover was first measured at the end of the first growing season in September 2004. Very little plant cover was observed during the first growing season. A photo chronology of plot 13, the 5 cm (2 inch) compost blanket treatment is shown in Appendix Table D3. During the spring of

2005 Miles City experienced excellent precipitation accumulation for establishment of the seeded species and monitoring occurring during the second growing season confirmed that perennial grasses responded to the flush of moisture. However, the robust vegetation cover observed in October 2005 has not persisted and monitored during 2006 suggested that many of the plants were dead. Few young plants establishing from seed were observed.

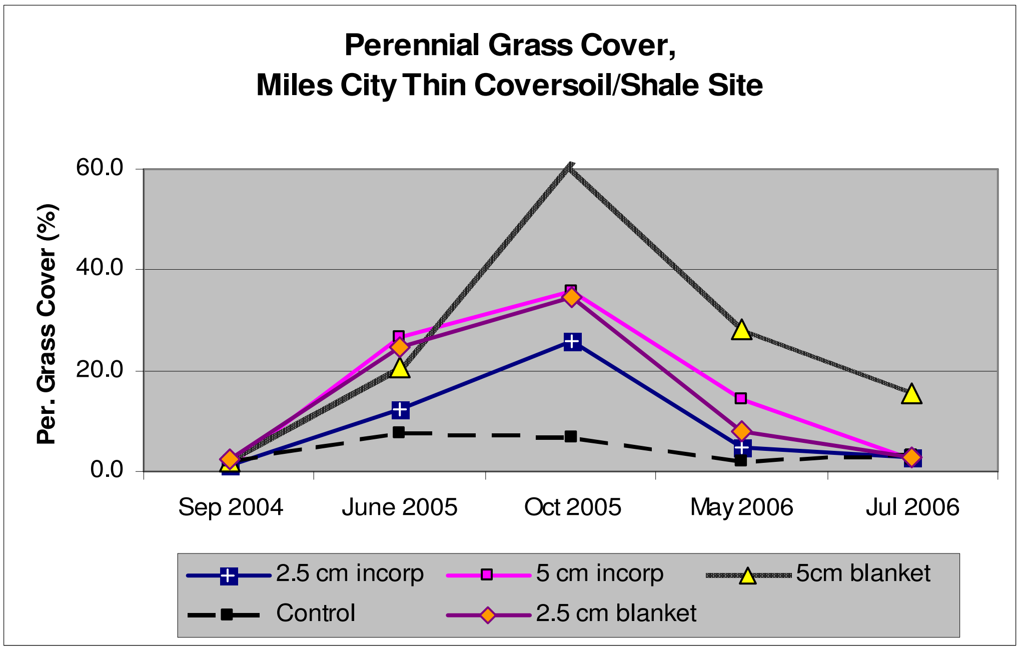


Figure 30. Response of perennial grasses to applied compost treatments compared to a control at the Miles City cut slope research sites on U.S. Highway 12.

The shale fill site (plots 16-20) at Miles City trended similarly to plots 11-15 with very little vegetation development observed during the first growing season, good vegetation development occurring during 2005 and declining perennial grass cover in 2006 during the third growing season (Figure 31). The supporting data is presented in Appendix B-2 and a photo chronology of plot 20 is shown in Appendix Table D4. The 5 cm (2 inch) compost blanket performed best during the second growing season while the 2.5 cm (1 inch) incorporated compost plot performed best during the third growing season. The declining performance of perennial grasses at this site suggests that permanence of the compost treatments is in question. Competition for nutrients and water with weedy species is a long-term concern.

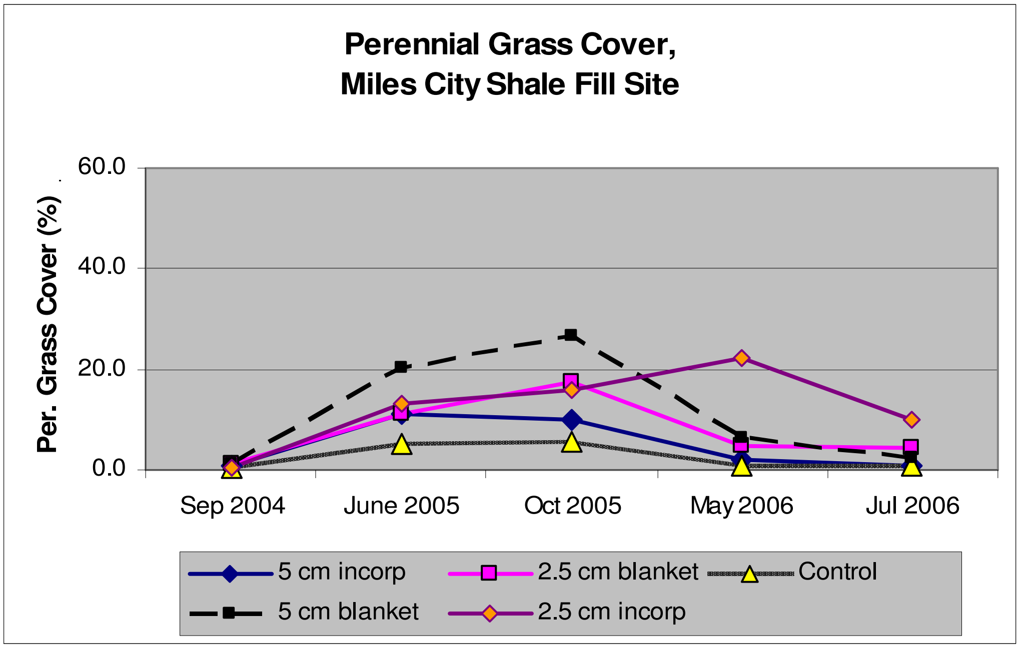


Figure 31. Response of perennial grasses to applied compost treatments compared to a control at the Miles City fill slope research sites on Interstate 94.

It is apparent that all plots with compost addition, whether it was a blanket or incorporated, had notably higher perennial grass cover than the control plots. The importance of compost incorporation compared with compost applied as a blanket appears to be insignificant. The strongest observation across all plots was that perennial grasses grew most rapidly in the compost blanket plots and developed more slowly in the compost incorporated plots, but by the third year of monitoring the incorporated plots exhibited better perennial grass cover than the blanket plots on several sites. The most compelling example of this trend was shown at the Loon Lake site where the blanket plots performed best in the first growing season, followed by a subsequent decline.

The rate of compost application used in the study was depths of 5 cm (2 inches), 2.5 cm (1 inch) and none (control). No compelling data set from either Happys Inn or Miles City suggests that the high rate of compost application is necessary or superior to the low rate of application. A general trend suggests that the high rate leads to more perennial grass cover; yet longer term monitoring may be required to prove out that assertion. Both the 2.5 cm (1 inch) and 5.0 cm (2 inch) applications rates were adequate and vastly superior to the control plot with no added organic amendment.

Plots 16 through 20 were split into 2 subplots. Rocky Mountain compost was used on the plots with an “a” following the plot number and Earth Systems compost was used on plots with a “b” following the plot number. A considerable difference between the two types of compost and perennial grass performance was not observed at the Miles City site. EKO Compost was used at the Happys Inn research site with excellent results. While physical, chemical or biological differences may exist between compost derived from different vendors these differences are inferred to be small and relatively inconsequential compared to the difference in perennial grass performance between compost treated plots and the controls without added compost. The addition of compost, either as a blanket or incorporated into the soil, had a profound response on the establishment of seeded perennial grasses.

4.4.2 Total Biomass Production

The amount of vegetation biomass observed on experimental plots was quantified during the 2005 growing season at the Happys Inn research site. Biomass production was reported as live vegetation from the current growing season and total vegetation cover representative of the total accumulation of live and decadent vegetation accumulation of all growing seasons. A total of 5 production measurements were collected from each plot along a fixed diagonal transect. Above ground biomass was collected according to life form and included: perennial grasses, annual grasses, weedy forbs, desirable forbs and litter. The amount of total vegetation production (including litter) and live vegetation production measured is reported in Figure 32. A significant residual plant litter component was observed. Live vegetation production on the 5 cm (2 inch) compost application rate plots was approximately 1500 kg/ha (1338 lbs/ac) while live vegetation cover on the 2.5 cm (1 inch) plots was approximately 500 kg/ha (446 lbs/ac). No large differences in production were observed between incorporated and blanket compost application.

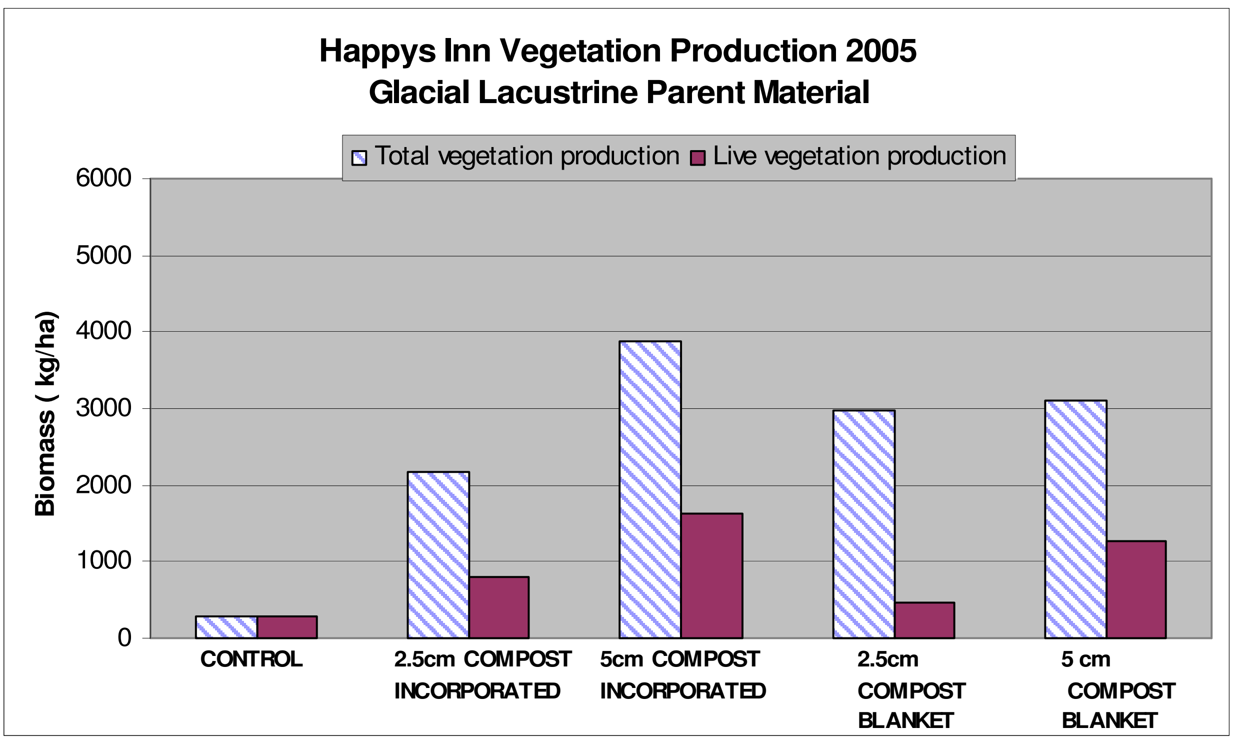


Figure 32. Total and live plant production measured at the Happys Inn glacial silt research sites along U.S. Highway 2 during 2005 at the end of the second growing season.

At the Happys Inn alluvial rock parent material plots 6-10 the 2.5 cm (1 inch) incorporated compost plot exhibited both total and live plant production levels similar to the control plot without added compost (Figure 33). In contrast, all the other compost plots showed live plant production of nearly 1000 kg/ha (892 lbs/ac) or better. The 5 cm (2 inch) compost blanket mean live plant production was 2240 kg/ha (1998 lbs/ac), by far the best response on the alluvial rock parent material. The progression of plant production on the 5 cm (2 inch) blanket plot is also visually observable in the Appendix Figure D2 photo chronology.

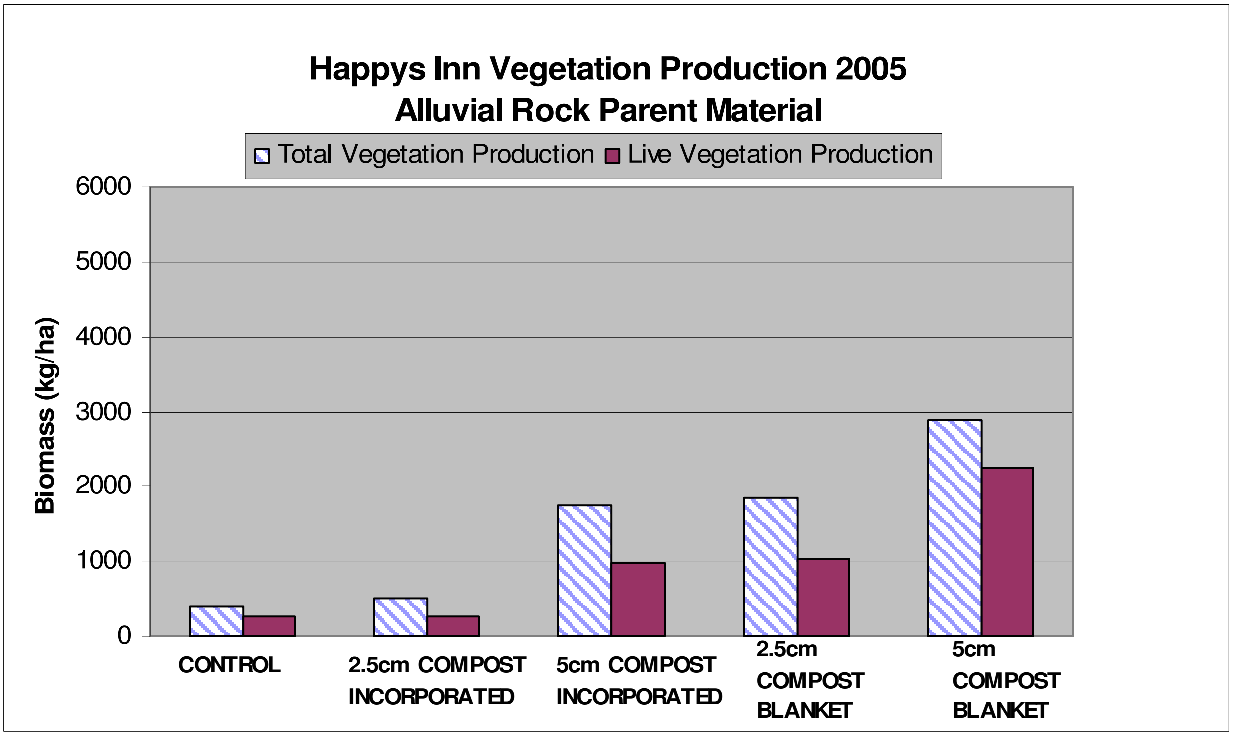


Figure 33. Total and live plant production measured at the Happys Inn alluvial rock research sites along U.S. Highway 2 during 2005 at the end of the second growing season.

Plant biomass observed at Miles City research sites is somewhat inconclusive other than demonstrating the effect of added compost compared to the controls. The control plots at both the thin coversoil/shale plots (Figure 34) and shale fill plots (Figure 35) exhibit approximately 1000 kg/ha (892 lbs/ac) of total plant production while most of the compost treated plots exhibit approximately 3000 kg/ha (2676 lbs/ac) total plant production. Clearly the compost stimulated plant growth, yet unfortunately much of the live and total plant production at the Miles City sites came from weedy species. This trend is discussed later in the report. The standout plot among the ten Miles City plots in terms of production is the 5 cm (2 inch) compost incorporated plot at the shale fill site (Figure 35) where both live and total plant production is highest of any Miles City test plots.

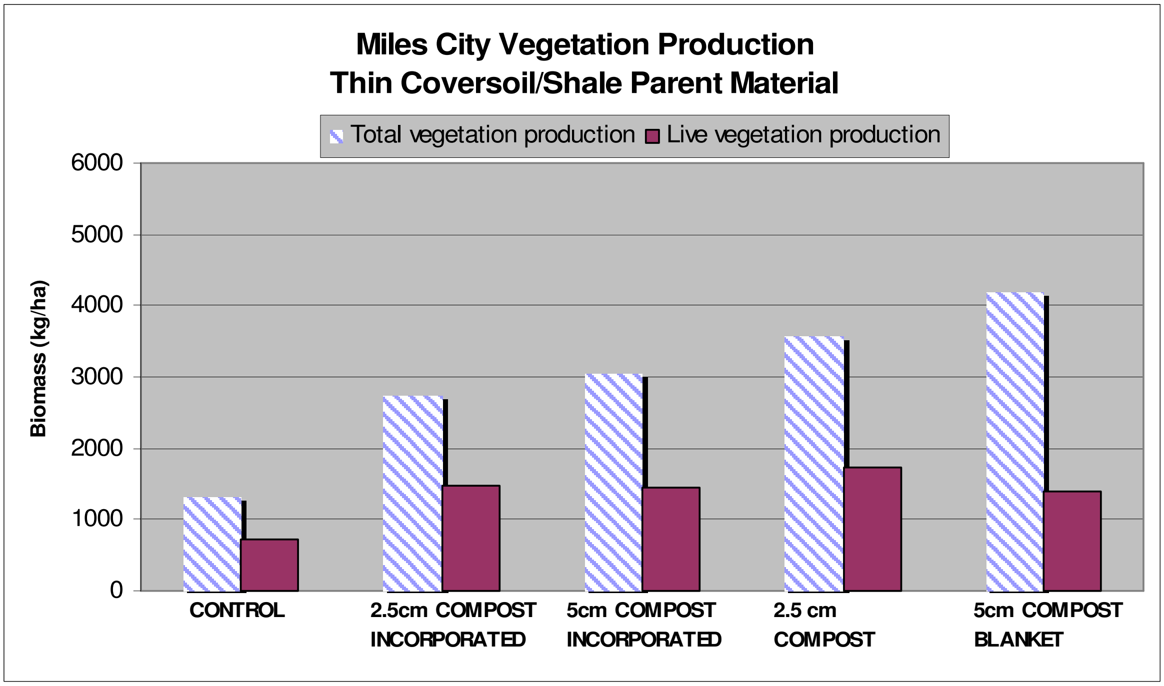


Figure 34. Total and live plant production measured at the Miles City thin coversoil/shale research sites along U.S. Highway 12 during 2006 at the end of the third growing season.

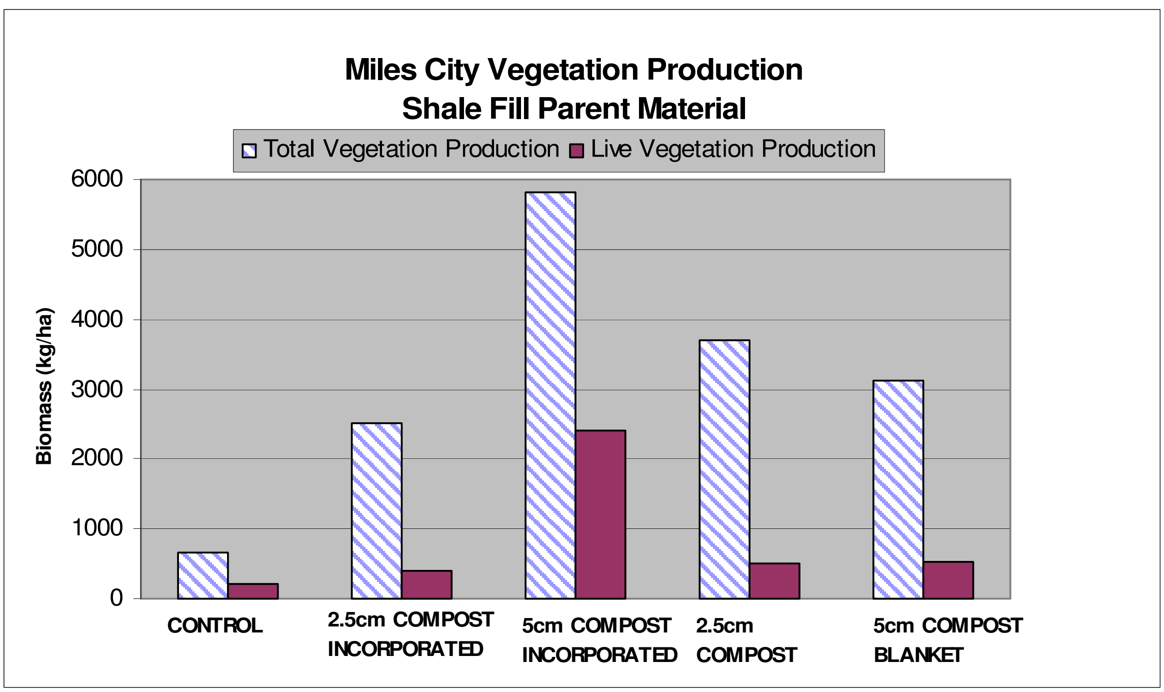


Figure 35. Total and live plant production measured at the Miles City shale fill research sites along Interstate 94 during 2006 at the end of the third growing season.

4.4.3 Plant Production by Life Form

Large differences in species composition were observed during the monitoring period at the different research sites. Vegetation production was measured in 2005 at the Happys Inn test plots, but deferred until 2006 at the Miles City test plots due to the carry over of negative effects of drought from the 2004 growing season. The compost treated plots near Happys Inn were dominated by the seeded species since the first growing season with little change in plant community composition other than the invasion of noxious weeds from adjacent areas (Figures 36 and 37). The compost treated plots at Miles City were dominated by annual grasses and weedy forbs (Figures 38 and 39).

Above ground biomass was measured in the second growing season (2005) at the Happys Inn research sites. Due to the robust growth of the seeded species at the Middle Thompson Lake sites (Figures 28 and 36) during the first growing season, all the compost treated plots exhibited abundant litter accumulation. This trend is corroborated by the vegetation cover data recorded in 2004 (Figure 28). Especially strong development of the seeded species on the 2.5 cm (1 inch) compost blanket treatment during 2004 contributed to the 2500 kg/ha (2230 lbs/ac) of litter and presumably to the comparatively low levels of perennial grass observed (~500 kg/ha; 446 lbs/ac).

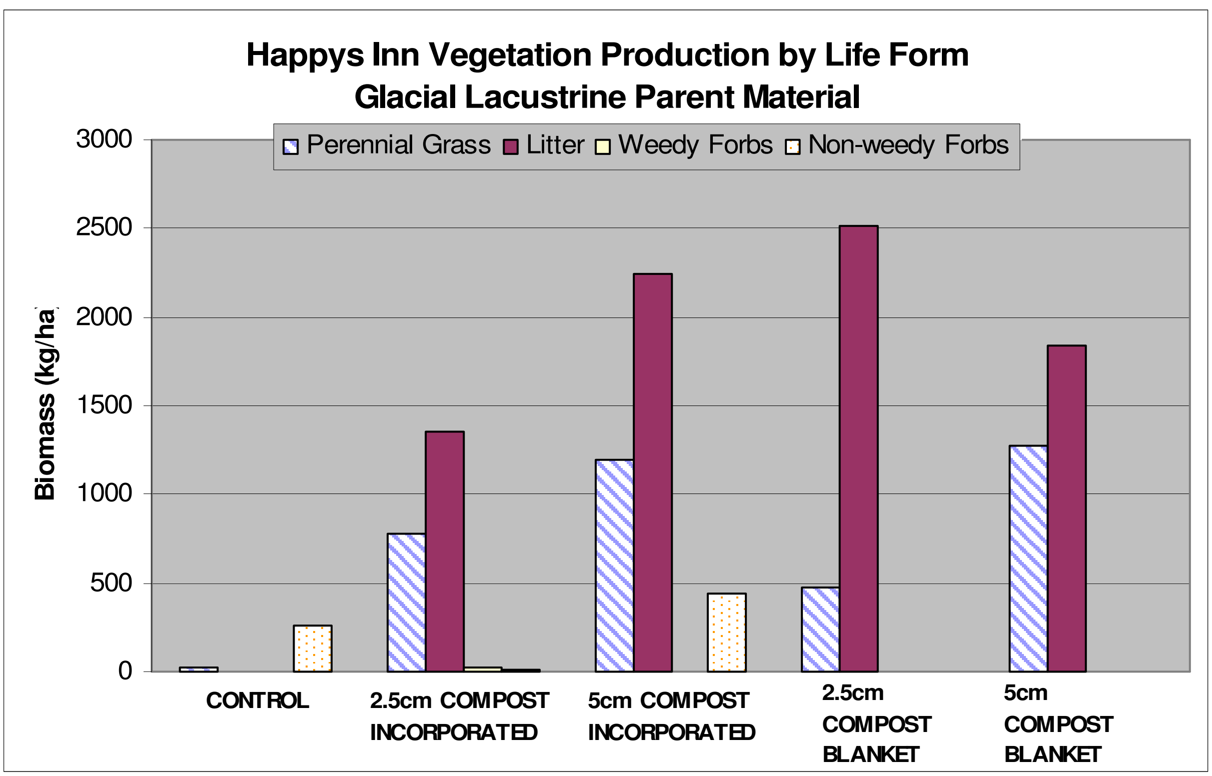


Figure 36. Plant production by life form at Happys Inn research plots 1-5 constructed on glacial silt parent material (2005 data).

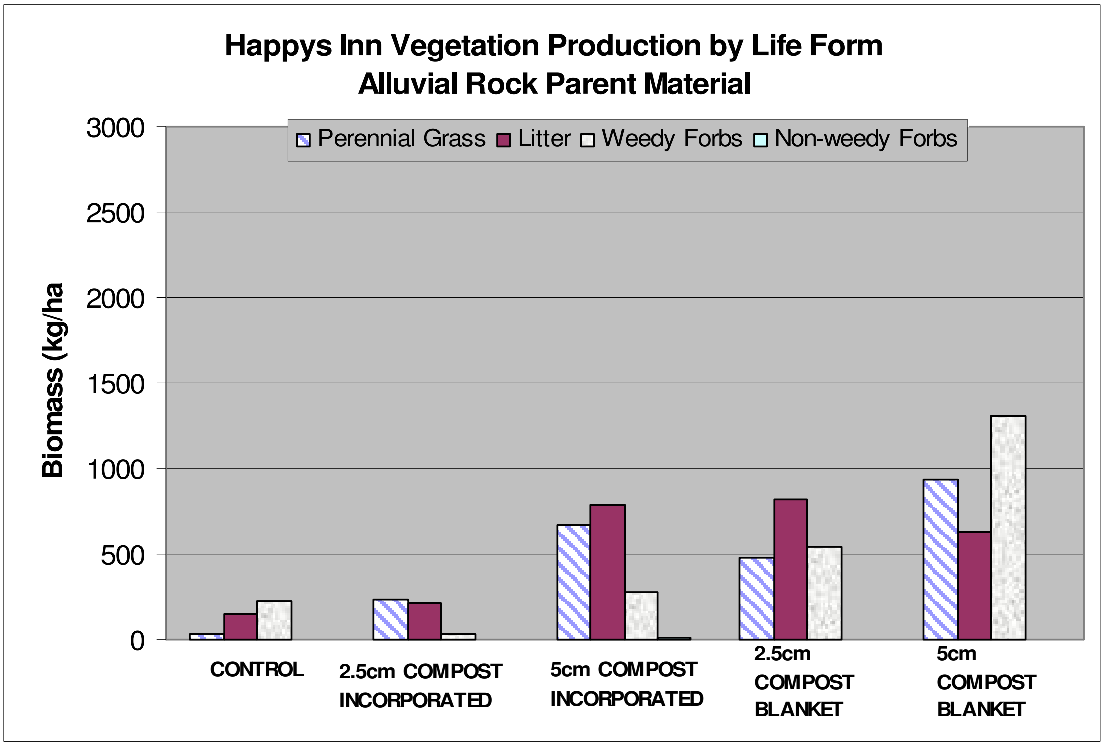


Figure 37. Plant production by life form at Happys Inn research plots 6-10 constructed on alluvial rock parent material (2005 data).

At the Loon Lake research site (Plots 6 - 10), vegetation establishment was somewhat less robust during the first growing season. The rocky parent material may have contributed to the relatively slower development of the seeded species and comparatively lower levels of biomass. Plant litter, however, was much less prevalent at the Loon Lake site in 2005 when above ground biomass was measured (Figure 37). Perennial grass biomass was best in the high compost application rate plots, whether applied as a blanket or tilled into the soil. Noxious weed invasion has also become a problem. Most plots exhibit some amount of spotted knapweed (*Centaurea stoebe*). The distribution of spotted knapweed was most pronounced in the upper portions of the plots 8, 9 and 10 at the Loon Lake Research site. Noxious weeds are migrating from a heavy knapweed infestation located less than 6 m upslope of these plots. The Montana Department of Transportation has contracted spraying for weeds in the vicinity of the plots but it is uncertain if the weed infestation near the research plots was sprayed with herbicide.

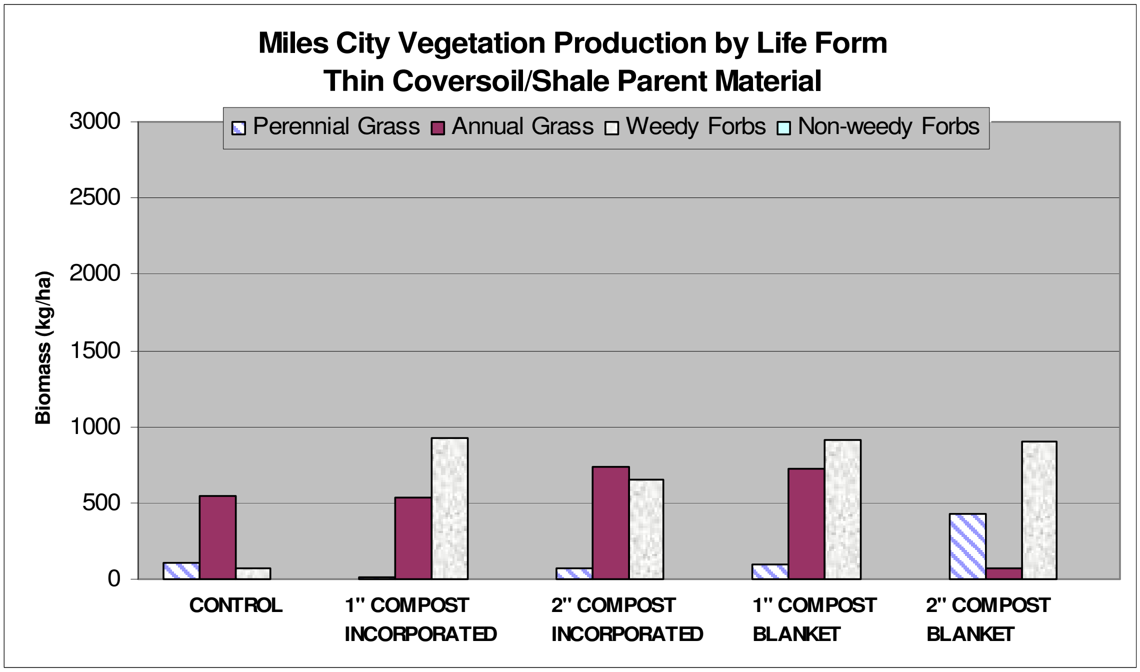


Figure 38. Plant production by life form at Miles City research plots 11-15 constructed on thin coversoil/shale parent material (2006 data).

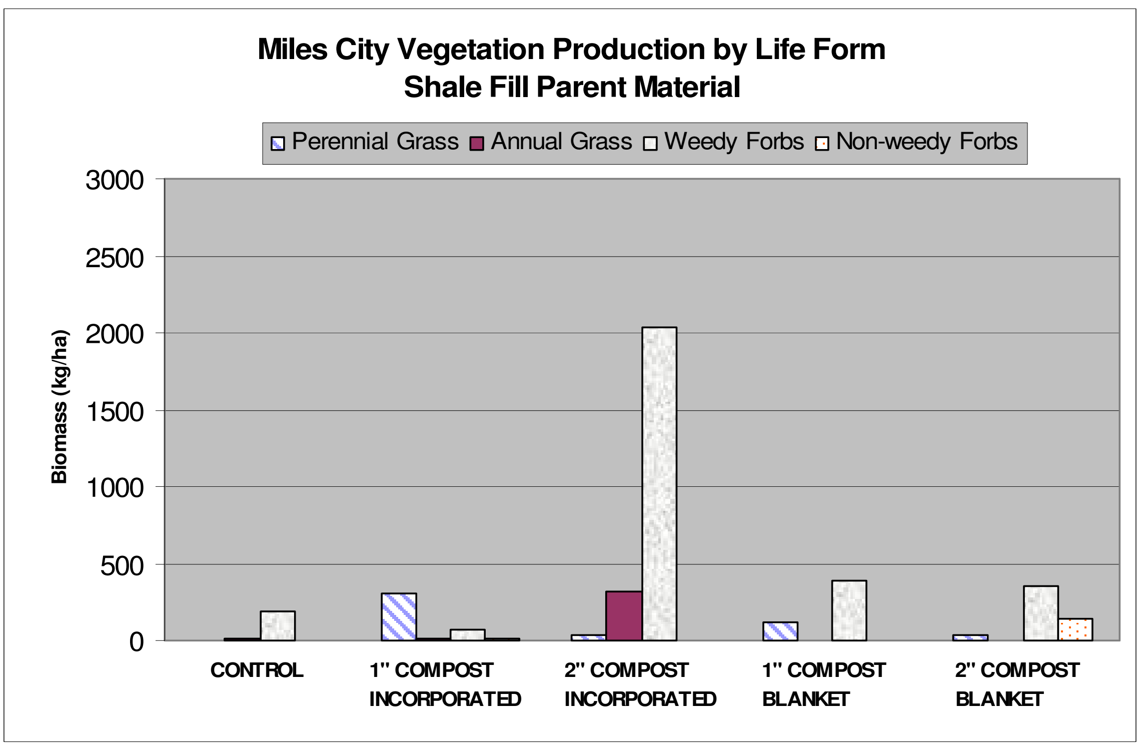


Figure 39. Plant production by life form at Miles City research plots 16-20 constructed on shale parent material (2006 data).

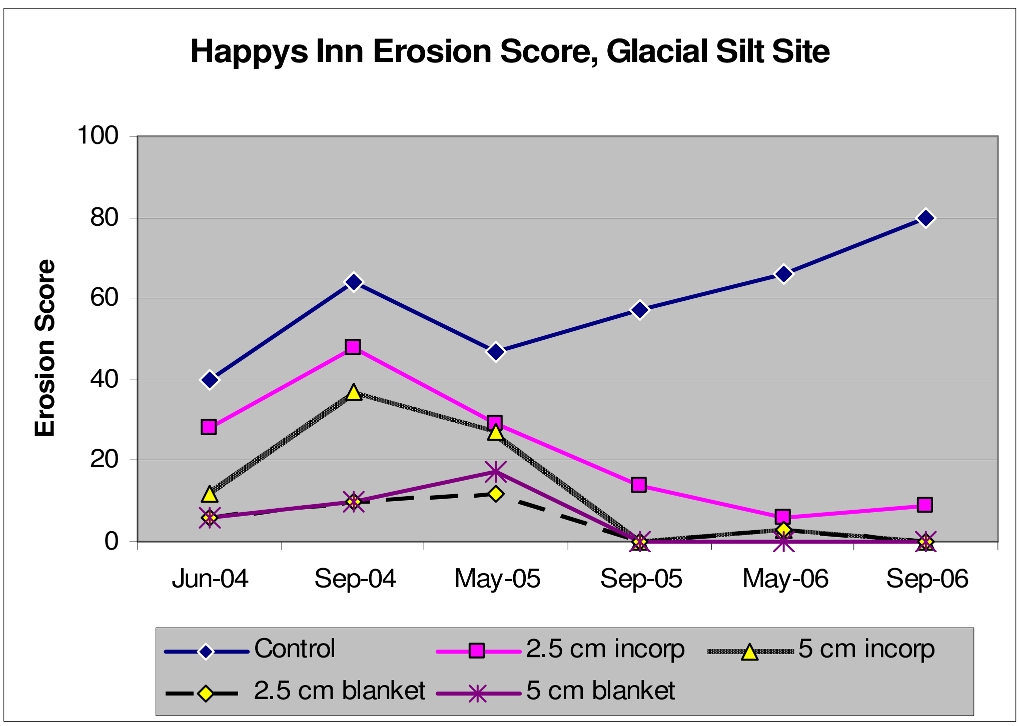
The disappointing performance of seeded species at the Miles City research sites cannot be conclusively attributed to either drought occurring during the first growing season or to the inhospitable characteristics of the parent material. However, poor performance of seeded species at the Miles City plots is unmistakable. Most of the compost treated plots are dominated by annual weeds and weedy forbs, notably cheatgrass (*Bromus tectorum*) and kochia (*Kochia scoparia)*. The surrounding area, most notably along the highway corridor, is weedy and likely serves at a conduit for weed seed distribution. In each block of research plots, one of the test plots exhibited reasonable perennial grass cover during the third growing season. On the thin coversoil/shale test plots along U.S. Highway 12, the 5 cm (2 inch) compost blanket treatment produced more than 400 kg/ha (357 lbs/ac) of perennial grass in addition to 900 kg/ha (803 lbs/ac) of weedy forbs (Figure 38). On the shale fill test plots along Interstate 94 the 2.5 cm (1 inch) incorporated compost plots exhibited 300 kg/ha (268 lbs/ac) of perennial grass production (Figure 39). Cheatgrass appeared to be most problematic on the U.S. 12 test plots constructed on low-quality, thin coversoil (Figure 38). The shale fill site only exhibited notable amounts of annual grass on the 5 cm (2 inch) compost blanket treatment (Figure 39). A photographic chronology of the vegetation development on each of the 'best performing' plots is presented in Appendix Figures D3 and D4. Optimistically, the compost treated plots support much greater vegetation cover compared to the untreated control plots and despite the undesirable species composition, erosion on the vegetated plots was reduced. The most troublesome trend observed was that perennial grasses that became well established and grew to maturity in the second growing season appear to have died back in the third year of monitoring. Long-term performance of the seeded species cannot be predicted, but their persistence is uncertain.

Since the unfavorable characteristics of the soil at the Miles City plots remained essentially unchanged after treatment, establishment of late successional perennial grasses may not be possible. The physical limitations caused by fine textured soil were not modified by soil amendment with compost. Similarly, the limitations on the seeded species by high SAR were unchanged. Additions of fertility caused by compost amendment served to greatly increase plant biomass during the research project, yet establishment of indigenous nutrient cycling through the symbiosis of soil microbes and plant appears to have been either unsuccessful or incipient. Casual observation of plant communities growing on similar parent materials adjacent to the research plots mirror the research findings: steep slopes are often intensively eroded and exhibit little perennial plant growth. Bare ground is common. Weedy annual plants are dominant. The species seeded during the research project are infrequently observed both on and off the experimental plots.

4.5 Erosion

Erosion monitoring was performed using a qualitative system developed by the U.S. Bureau of Land Management for rangeland (Clark, 1980). The system uses seven different measurements: plant litter movement, surface rock movement, pedestalling, surface flow patterns, rill development, gully development and depth of surface soil deposits. Within each category the degree to which erosional processes are occurring is estimated. The total score is determined by combining the 7 category scores to arrive at an overall rating with a low score attributed to low levels of erosion. Five overall score categories are reported in 20 point intervals: 1-20 points-stable, 21-40 points slight erosion, 41-60 points-moderate erosion, 61-79 critical erosion and 80-100-severe erosion. Erosion on all plots was qualitatively evaluated during each site visit. Results from all of the erosion evaluations from 2004-2006 are reported in Appendix C, Tables C1 and C2.

The Middle Thompson Lake test plots constructed on glacial silt parent material retarded sediment loss both by live vegetation canopy cover and plant litter protecting the soil surface. The erosion classification recorded was 'stable' on all of the compost treated plots during 2006 while the untreated control exhibited 'moderate' to 'critical' erosion during the period of monitoring (Figure 40). During the first year of erosion monitoring all sites exhibited surface roughness residual from plot construction. All plots were tilled on the contour during plot construction in 2003. Erosion increased between June 2004 and September 2004 as the surface roughness dissipated. The compost treated plots exhibited a maximum erosion score in September 2004 and then progressively improved during monitoring. Very little erosion was observed during the final monitoring event in September 2006. Conversely, the control plot continuously degraded over time. Notable amounts of surface rilling were observed on the control plot in September 2006. The incorporated compost plots exhibited slightly higher levels of erosion than the compost blanket plots, although the differences were most pronounced during the first year of monitoring.



Erosion scores are classified into erosion condition classes (Clark, 1980) as follows:

Score:	Class:
1 -20	Stable
21-40	Slight
41-60	Moderate
61-80	Critical
81-100	Severe

Figure 40. Erosion condition assessment at the glacial silt research site, Plots 1-5 during 3 years of monitoring.

The alluvial rock research plots exhibited less distinct trends in erosion due in part to the significant infiltration capacity of the parent material. High rock content coupled with coarse textured soil ensured that limited erosion would result from any of the experimental plots including the control. Most of treated plots exhibited either 'stable' or 'slight' erosion condition during 3 years of monitoring (Figure 41). The surface of the control plot provided the highest erosion score during September 2006. While stormwater runoff from the alluvial rock research site was not highlighted as a problem prior to plot construction, monitoring of erosional condition was performed to provide data for comparative purposes.

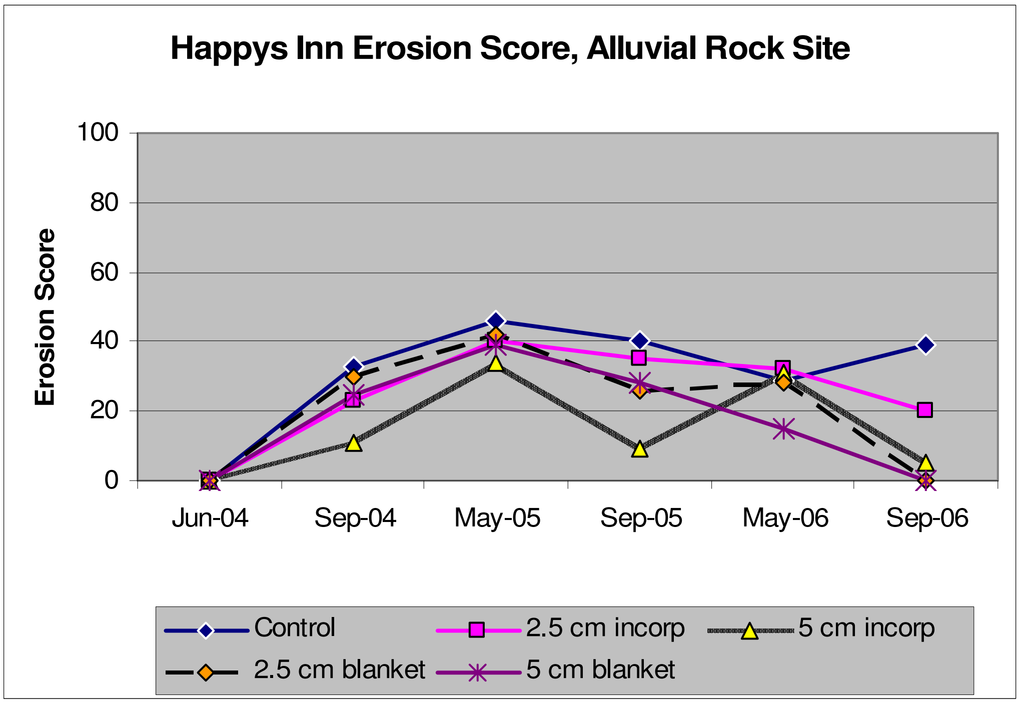


Figure 41. Erosion condition assessment at the alluvial rock research site, Plots 6-10 during 3 years of monitoring.

Erosion monitoring was performed at the Miles City research sites in accordance with the same methodologies used at Happys Inn. The U.S. Highway 12 test plots were monitored 6 times during the 3 year period of performance evaluation (Figure 42). Similar to the Happys Inn research sites, the compost treated plots exhibited less erosion than the untreated control. The 5 cm (2 inch) compost blanket consistently exhibited the lowest erosion level with the exception of the July 2006 monitoring event. Both the 5 cm (2 inch) compost treatments were 'stable' while the 2.5 cm (1 inch) compost treatments were slightly erosive. The control plot displayed 'moderate' levels of erosion during the final monitoring event.

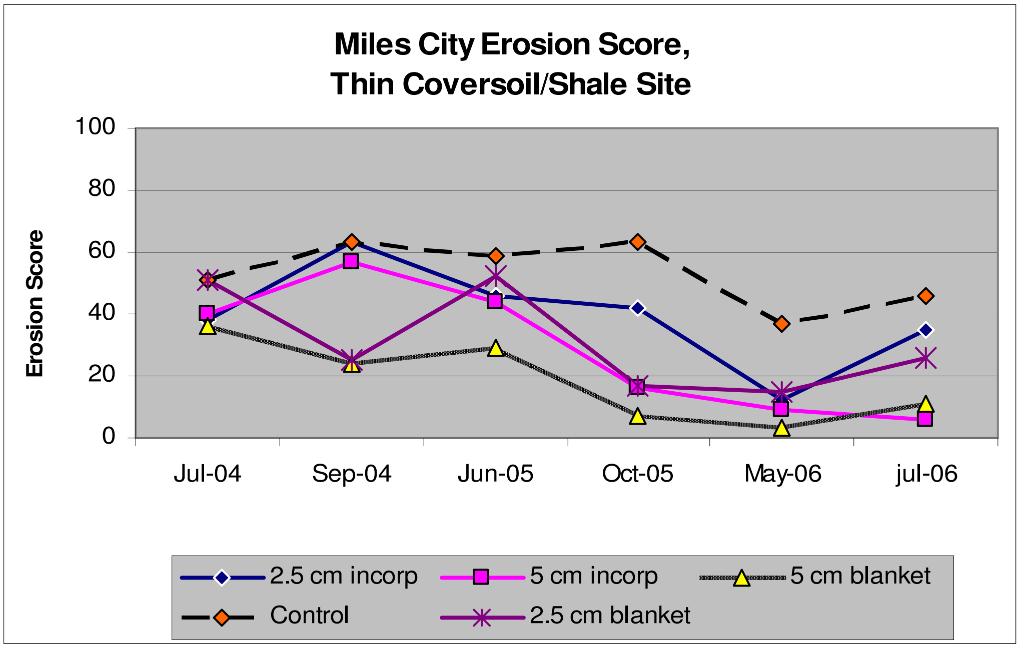


Figure 42. Erosion condition assessment at the thin coversoil/shale research site, Plots 11-15 during 3 years of monitoring.

Observations from the Interstate 94 shale fill research site report perhaps the most interesting trends of all the erosion data collected (Figure 43). All the compost treated plots revealed higher levels of erosion during the first monitoring event in July 2004 compared with the control. The compost treated plots were moderately erosive while the control plot was slightly erosive. Eleven months later in June 2005 the trend had been reversed. During the final 3 monitoring episodes the treated plots became progressively more stable while the control plot became more erosive. The 5 cm (2 inch) incorporated compost treatment achieved low levels of erosion by October 2005 and through the end of the monitoring period. Of particular interest, the other three compost treated plots exhibited increased levels of erosion between the 5th and 6th monitoring events. The reason for this upward step in erosion is unknown, but may relate to the decline in vegetation condition previously discussed.

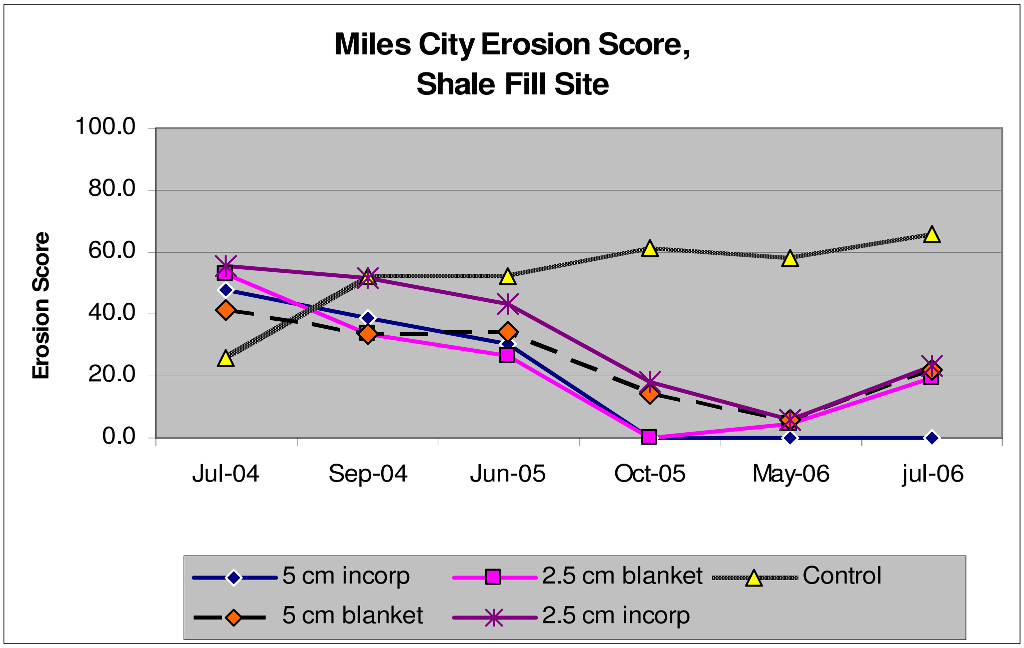


Figure 43. Erosion condition assessment at the shale fill research site, Plots 16-20 during 3 years of monitoring.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Erosion from steep slopes is a prevalent problem at construction sites and along transportation corridors. Replacement of topsoil on steep slopes is often impractical. Consequently, establishment of perennial native species on disturbed slopes has proven challenging, especially when south-facing slopes are comprised of parent materials inhospitable to plant growth. Prior experience of the Montana Department of Transportation has proven that glacial till, marine shale and alluvial rock slopes can be difficult to revegetate.

Compost application on steep slopes is a viable technique for vegetation reestablishment and stormwater control. Compost suitable for use as a soil amendment is widely available throughout Montana. Equipment is available to safely apply compost using pneumatic blower trucks. Compost can be applied to the soil surface as a blanket or subsequently incorporated into the soil using specialized tilling equipment. After three years of vegetation, erosion and soil chemistry monitoring neither the compost blanket nor incorporated compost treatments are notably different from each other, but the resulting native vegetation on all compost treated plots is markedly better than control plots lacking compost. Erosion from steep slopes treated with compost has been reduced compared to adjacent control lacking compost.

5.1 Happys Inn Equipment Performance Summary

The blower truck utilized for this study has the capability to apply compost or similar materials to nearly any slope up to steepness at which the applied materials will slough off due to gravity. The blower has sufficient power to blow compost through at least 100 m (328 ft) of hose and likely considerably further. The factory specification for the unit used (EB-30) suggests full-scale application rates could be double the rates at which the compost was applied to the research plots. Highway construction contractors will have to evaluate this type of equipment as they would any other: production versus cost. The blower trucks will be capable of applying compost where other means are lacking or are inefficient.

The use of snowcat type equipment for tillage on steep slopes is viable but productivity and job quality may suffer if the construction site contains abundant cobble and boulders. Conditions at Loon Lake were close to the limit of the snowcat used. It is apparent that some type of suspension would be very beneficial for work on similar slopes containing considerable cobble and boulders. In finer textured materials without rock the snowcat performed admirably and was able to till on the contour on 3H:1V slopes. Contour tillage with the snowcat on the 2H:1V alluvial rock was unsuccessful.

5.2 Miles City Equipment Performance Summary

As noted during the construction of the Happys Inn sites the blower truck utilized for this study had the capability to apply compost or similar materials to nearly any slope. The unit had no difficulty blowing either wet (Earth Systems) or dry (Rocky Mountain Compost) materials.

The use of AEBI tractors for tillage on steep slopes similar to those at the Miles City plots is viable. It is highly likely the TT88 could perform well on the shale dominated materials up to at least a 50 percent slope. Units with four wheel steering (TT70, TT70S, TT75 and

TT270) would no doubt enhance productivity by allowing tighter turning. The four-wheel steer may also increase control while tilling across slope. The performance of this unit on sites that contain abundant cobble and boulders is unknown. Conditions similar to those encountered at the Loon Lake site near Happys Inn would at best present a number of control problems and in the worst case, insufficient traction could prevent traverse up-slope.

5.3 Soil Chemistry Summary

The pre-treatment and post-treatment soil chemical data suggest the fertility and organic matter content was improved by compost addition. Organic matter levels, predictably, were elevated in the soil 2 years after compost addition. Levels of plant-available NO_3-N were similar in the controls and treated plots, but levels of both total carbon and total nitrogen in the treated soil were elevated by organic addition. Potassium and especially phosphorous persisted in the soil treated with compost. The long-term pool of nutrients, organic carbon and nitrogen are expected to serve as a long-term foundation for microbiological processes in soil and the associated above ground plant growth. Unfavorable saline soil chemistry was sometimes improved by compost addition.

Soil analyses indicate that while the two Miles City sites are generally similar, the I-94 fill site exhibits more harsh soil conditions than the Highway 12 cut area. It had higher mean SAR (30.6 versus 14.0, respectively) and higher mean electrical conductivity (6.4 versus 2.1 dS/m). The I-94 site also had higher mean nutrient concentrations for N (95.2 versus 10.2 mg/kg (ppm)), P (8.5 versus 3.9 mg/kg (ppm)), and K (218 versus 193 mg/kg (ppm)). At the Happys Inn lacustrine sediment research site SAR was reduced from an average of 11.3 to 1.1 following compost addition. Coincidentally, the intervening 2 year period also experienced above average rainfall, so the true compost effect on SAR is unquantified. A SAR change at the Miles City test plots was undetected with compost treated plots exhibiting both higher and lower SAR values compared to the control.

5.4 Vegetation Performance

Vegetation performance was greatly enhanced on all plots treated with compost as compared to the control plots that received no compost treatment. Both Happys Inn and Miles City research plots treated with compost responded with robust plant growth. Establishment and persistence of seeded species at the Happys Inn sites was excellent while persistence of seeded species at the Miles City sites was poor. To date, results indicate that the differences between the two compost amendment techniques, blanket versus incorporated, are subtle.

Happys Inn plots 8 through 10 were affected by an infestation of spotted knapweed that had migrated in from a large infestation on neighboring property. These aggressive noxious weeds may require herbicide application to control the infestation. Miles City plots had a number of annual grasses and weedy forbs present in 2006. This may be due to the drought conditions favoring annual plants. Overall, native plant communities established on the Happys Inn research plots were on a trajectory to becoming stable and self-perpetuating. At Miles City the success and persistence of seeded species is uncertain. Several of the compost treated plots have very few perennial grasses remaining of those seeded at the time of plot construction. Other test plots have a sparse but adequate distribution of perennial grasses. The robust growth and persistence of annual grasses and weedy forbs also suggests the soil is suitable for some plant growth. While species identification was outside the scope on monitoring, the trend toward increasing cover of annual weeds is unmistakable. While some of the seeded species have persisted through several difficult climatic years with low precipitation and grown to maturity, their ability to produce seed and colonize adjacent land dominated by annual weeds remains an untested theory. Additional monitoring is warranted to confirm or refute treatment effectiveness, and to track the persistence and expansion of seeded species.

5.5 Erosion

Addition of compost, by blanket or incorporation into soil, greatly reduced soil loss on the research plots. Establishment of vegetation on the compost treated plots was a major factor in the reduction of erosion. Changes in the physical and chemical properties of the soil by compost contributed significantly to enhanced infiltration characteristics and improved nutrient status. Compost blanket treatments, in particular, protected the mineral soil from detachment by providing a barrier against raindrop impact. The most important control on erosion appears to be the rapid and robust establishment of vegetation caused by compost addition and leading to the creation of soil structure, promoting infiltration and protection of the soil surface with both live plant matter and litter from prior years.

5.6 Recommendations

Specifications for compost application methods and rates of application should be developed and implemented in future construction projects. Rates of surface compost application used in this research project, 2.5 cm (1 inch) and 5 cm (2 inch), were developed based on literature review and analysis of the experience of Departments of Transportation outside Montana. This research has shown that compost incorporation is generally as effective as blanket application, but not required. Research has also demonstrated that more plant biomass results from the higher 5 cm (2 inch) application rate, but that the 2.5 cm (1 inch) application rate is quite effective. The specification for south-facing, glacial till in Western Montana should employ a 2.5 cm (1 inch) blanket of compost with seed placed in the applied compost or on the bare mineral soil underneath the compost. The 2.5 cm (1 inch) specification may perform adequately on alluvial rock parent material or other coarse substrates, but the 5 cm (2 inch) application rate appears to provide more plant cover and perennial grass production.

Future refinement of the compost specification should be made based on new research and pending the long-term outcome of the research plots at Miles City. No clearly successful revegetation prescription using compost was distilled from test plots constructed on saline marine shale. Conventional soil salvage and replacement techniques should be employed pending development of a compost amendment or amendment/soil hybrid technique.

5.7 Future Research

Two new areas of inquiry have resulted from this research: plant performance at rates of compost addition less than 2.5 cm (1 inch) and stabilization of compost blankets from wind erosion. Since compost blankets appear to be as effective as compost incorporated into the soil there are several reasons to emphasize blankets over incorporated compost. Compost blankets are less costly since they do not require the services of a specialty tillage contractor. Operator safety is also improved by not putting equipment and operators on steep slopes. However, drying of compost blankets coupled with high wind creates a potential for loss of surface applied compost prior to emergence and establishment of vegetation. Retention of compost blankets on the soil surface is necessary. Some portion of the compost blankets installed at the Miles City research site was lost to wind erosion. The amount of compost lost was unquantifiable. Secondly, the robust development of vegetation at the Happys Inn research sites using 2.5 cm (1 inch) applications of compost suggests adequate amounts of plant growth may be achievable using less material. Compost blanket rates between 0 and 2.5 cm (1 inch) should be evaluated in future research to develop an optimum application rate in consideration of cost, parent material and local climate. The persistence of seeded species in soil or parent material derived from marine shale with high SAR remains as an unanswered research question.

6.0 REFERENCES CITED

Alden, W.C. 1953. Physiography and Glacial Geology of Western Montana and Adjacent Areas. U.S. Geological Survey Professional Paper 231. Pages 134-136.

American Society of Agronomy (ASA), Soil Science Society of America. 1986. Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Second Edition. Madison, WI.

American Society of Agronomy (ASA), Soil Science Society of America. 1982. Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, Second Edition. Madison, WI.

American Society for Testing Materials (ASTM). 2002. Standard Test Method for Particle-Size Analysis of Soils, D-422-63. West Conshohocken, Pennsylvania.

Caprio, J.M. 1971. The Solar-Thermal Unit theory in relation to plant development and potential evapotranspiration. Montana Agricultural Experiment Station Circular 251. Montana State University, Bozeman, MT.

Caprio, J.M., D.I Cooksey, C.M. Erlien, J.S. Jacobsen, G.A. Nielsen, and R.R. Roche. 2001. MAPS (Montana Agricultural Potentials System) Atlas Version 6.0. A land and climate information system. Montana State University, Bozeman, MT.

Clark, R. 1980. Erosion Condition Classification System. U.S. Department of the Interior Bureau of Land Management. Technical Note #346.

Daubenmire, R. 1968. Plant communities: a textbook of plant synecology. Harper and Row, New York, NY 300pp.

Demars, K.R. and R. Long. 1998. "Field Evaluation of Source-Separated Compost and CONEG Model Procurement Specifications for Connecticut DOT Projects". National Transportation Library Report Number JHR 98-264. University of Connecticut and Connecticut Department of Transportation. 93 pp.

Glanville, T.D., T.K. Richard and R.A. Persyn. 2003. "Impacts of Compost Blankets on Erosion Control, Revegetation, and Water Quality at Highway Construction Sites in Iowa". Iowa State University, Agriculture and Biosystems Engineering Department. Ames, Iowa 67 pp.

Idaho Transportation Department. 1997. "Erosion Control and Revegetation Demonstration Project Report, Horseshoe Bend Hill, Idaho State Highway 55", 6 pp.

Jennings, S.R., J.D. Goering, P.S. Blicker, and J.J. Taverna. 2003. Evaluation of organic matter addition and incorporation on steep cut slopes phase I: Literature review and potential application equipment evaluation. Montana Department of Transportation Research Program, Helena MT.

Ross, C. P., D.A. Andrews, and I.J. Witkind. 1955. Geologic Map of Montana. U.S. Geological Survey.

Sollenger, D.A. 1987. "Erosion of Compost and Co-Compost Materials for Highway Construction – Phase I". California Department of Transportation, Phase I Final Report, 56p.

Texas Transportation Institute. 1995. "The Use of Compost and Shredded Wood on Rights-Of-Way for Erosion Control". Report 1352-2F. FHWA/TX-97/1352-2F, 75pp.

U.S. Department of Agriculture and the United States Composting Council. 2001. Test Methods for the Examination of Composting and Compost (TMECC). W. H. Thompson, ed.

U.S. E.P.A. 1997. "Innovative Uses of Compost; Erosion Control, Turf, Remediation, and Landscaping". Publication: EPA530-F-96-043. Washington D.C. 8 pp.

U.S. E.P.A. 2006. National Pollution Discharge Elimination System, Construction Site Stormwater Runoff Control, Compost Blanket. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/compostblanket.cfm.

Vuke, S.M., S.J. Luft, R.B. Colton, and E.L. Heffern. 2001. Geologic map of the Miles City 30' x 60' Quadrangle, Eastern Montana. Montana Bureau of Mines and Geology Open File No. 426. Butte, Montana.

APPENDICES

APPENDIX A

Soil and Compost Analytical Data

Table A1. Happys Inn coarse rock fragment analysis, MDT Study - Method ASTM D422-63.

Sample	Site	> 2 mm Container tare (g)	Container Tare plus > 2mm fraction (g)	Rock size Max size (cm)	< 2 mm Container tare (g)	Container tare plus < 2mm fraction (g)	% Rock (mass)
Plot1	Glacial silt	13.50	23.56	1.0	17.36	845.97	1.20
Plot2	Glacial silt	13.52	15.04	1.0	18.39	837.54	0.19
Plot3	Glacial silt	13.53	19.92	1.0	18.39	984.57	0.66
Plot4	Glacial silt	13.48	56.73	1.0	18.36	821.88	5.11
Plot5	Glacial silt	13.49	27.42	1.0	18.34	775.4	1.81
Plot6	Alluvial rock	13.53	1545.82	7.0	18.40	646.74	70.92
Plot7	Alluvial rock	13.57	1486.36	9.0	18.42	897.62	62.62
Plot8	Alluvial rock	13.60	1241.83	10.0	18.44	651.06	66.00
Plot9	Alluvial rock	13.60	1012.70	8.0	18.46	1115.45	47.66
Plot10	Alluvial rock	13.63	1101.06	4.5	18.46	473.79	70.49
Plot10D	Alluvial rock	13.68	1142.17	12.0	18.46	429.80	73.29

Table A2. Happys Inn MDT Compost Analysis.

				TMECC Method 03.09	ASA/SSSA 21-2.2	TMECC Method 03.09	ASA/SSSA	TMECC
11/25/2003 Dried at 70° C	**Container Tare**	**Container Plus Wet Compost**	**Container Plus Oven Dry Compost**	**Gravimetric Water (as received basis)**	**Gravimetric Water (dry basis)**	**Total Solids (wet basis)**	**% of Total Sample (> 4.75 mm plus < 4.75mm), (dry basis)**	**% of Total Sample (> 4.75 mm plus < 4.75mm), (wet basis)**
Sample	(g)	(g)	(g)	(%)	(%)	(%)	(%)	(%)
C-1 >4.75mm	8.93	64.48	47.13	31.23	45.42	68.77	15.29	12.78
C-1 <4.75mm	8.82	387.88	220.52	44.15	79.06	55.85	84.71	87.22
C-1 (all)	8.89	352.92	200.36	44.34	79.68	55.66		

Water determined after drying in oven for 24+ hours at 70 deg C.
Reported as g/g wet basis per Test Methods for the Examination of Composting and Compost (USDA and USCC, 2001) and Gardner (ASA, 1986) method for water content in soil as % of dry mass of soil

Table A3. Chemical characteristics of soil substrates prior to construction of research plots near Happys Inn, U.S. Highway 2.

Sample I.D.	Site	Mg mg/L	Na mg/L	Ca mg/L	EC (dS/m)	pH	SAR
MP 77 Plot 1	Glacial silt	11	209	8	1.00	8.7	11.1
MP 77 Plot 2	Glacial silt	13	455	5	1.97	8.6	24.5
MP 77 Plot 3	Glacial silt	38	251	58	1.56	8.2	6.3
MP 77 Plot 4	Glacial silt	58	391	26	2.09	8.3	9.8
MP 77 Plot 5	Glacial silt	48	163	14	1.16	8.4	4.6
MP 69 Plot 6	Alluvial rock	8	6	54	0.40	8.1	0.2
MP 69 Plot 7	Alluvial rock	16	8	83	0.58	8.0	0.2
MP 69 Plot 8	Alluvial rock	16	6	110	0.65	8.4	0.2
MP 69 Plot 9	Alluvial rock	13	5	93	0.56	8.5	0.1
MP 69 Plot 10	Alluvial rock	20	6	79	0.54	8.5	0.2
MP 69 Plot 10 Duplicate	Alluvial rock	19	6	72	0.55	8.5	0.2

Table A4. Nutrient levels in soil substrates prior to construction of research plots near Happys Inn, U.S. Highway 2.

Sample I.D.	Site	NO_3-N mg/kg	P mg/kg	K mg/kg
MP 77 Plot 1	Glacial silt	0.5	3.3	66
MP 77 Plot 2	Glacial silt	2.1	2.2	62
MP 77 Plot 3	Glacial silt	1.0	5.0	60
MP 77 Plot 4	Glacial silt	0.4	1.4	68
MP 77 Plot 5	Glacial silt	0.3	1.7	50
MP 69 Plot 6	Alluvial rock	4.3	6.1	48
MP 69 Plot 7	Alluvial rock	5.9	8.6	52
MP 69 Plot 8	Alluvial rock	7.3	20.3	134
MP 69 Plot 9	Alluvial rock	2.7	6.1	68
MP 69 Plot 10	Alluvial rock	3.1	7.5	46
MP 69 Plot 10 Duplicate	Alluvial rock	3.1	6.8	52

Table A5. Physical characteristics of soil substrates prior to construction of research plots near Happys Inn, U.S. Highway 2.

Sample I.D.	Site	Sand %	Silt %	Clay %	Saturation Percentage (% H_2O)	Texture
MP 77 Plot 1	Glacial silt	2	78	20	39.1	Silt loam
MP 77 Plot 2	Glacial silt	< 1	84	16	37.9	Silt loam
MP 77 Plot 3	Glacial silt	4	86	10	38.3	Silt
MP 77 Plot 4	Glacial silt	2	84	14	40.7	Silt loam
MP 77 Plot 5	Glacial silt	2	86	12	39.0	Silt loam/Silt
MP 69 Plot 6	Alluvial rock	66	26	8	17.9	Sandy loam
MP 69 Plot 7	Alluvial rock	68	26	6	18.4	Sandy loam
MP 69 Plot 8	Alluvial rock	56	34	10	31.6	Sandy loam
MP 69 Plot 9	Alluvial rock	80	16	4	19.9	Loamy sand
MP 69 Plot 10	Alluvial rock	70	24	6	20.1	Sandy loam
MP 69 Plot 10 Duplicate	Alluvial rock	69	27	4	19.4	Sandy loam

Table A6. Chemical characteristics of compost used in Happys Inn research plots, U.S. Highway 2.

Sample I.D.	pH[1]	EC[2] (dS/m)	Total C[3] (%)	Total N[4] (%)	H_2O[5] (%)	TKN % N	Organic Matter %
EKO compost	6.8	1.01	28.0	1.25	31.7	0.82	36.9

1 TMECC method 04.11 (USDA and USCC, 2001)
2 TMECC method 04.10 (USDA and USCC, 2001)
3 TMECC method 04.01-A (USDA and USCC, 2001)
4 TMECC method 04.02-D (USDA and USCC, 2001)
5 TMECC method 03.09, ASA/SSSA 21-2.2 (1986)

Table A7. Miles City coarse rock fragment analysis, MDT Study - Method ASTM D422-63.

Sample	Site	> 2 mm Container Tare (g)	Container Tare plus all (g)	> 2 mm (g)	Container tare plus > 2mm fraction (g)	% Rock (mass)
Plot 11	Coversoil/shale	17.21	815.05	7.44	24.65	0.93
Plot 12	Coversoil/shale	17.25	815.87	32.2	49.55	4.04
Plot 13	Coversoil/shale	16.39	933.81	18.21	34.60	1.98
Plot 13D	Coversoil/shale	16.41	836.55	12.30	28.71	1.50[#]
Plot 14	Coversoil/shale	17.27	784.55	11.15	28.42	1.45
Plot 15	Shale fill	16.39	768.80	6.91	23.30	0.92
Plot 16	Shale fill	17.24	762.44	130.02	147.26	17.45
Plot 17	Shale fill	16.48	754.56	325.22	341.70	44.06
Plot 18	Shale fill	17.32	768.55	123.79	141.11	16.48
Plot 19	Shale fill	16.42	760.16	201.00	217.42	27.03
Plot 20	Shale fill	102.35	669.19	366.49	468.84	64.64[##]

\# Relative Percent Difference = 27.6 %

\## Highly aggregated

Table A8. Physical characteristics of soil substrates prior to construction of research plots near Miles City, MT.

Sample I.D.	Site	Sand %	Silt %	Clay %	Saturation Percentage (% H_2O)	Texture
Plot 11	Coversoil/shale	28	43	29	50.2	clay loam
Plot 12	Coversoil/shale	28	43	29	74.2	clay loam
Plot 13	Coversoil/shale	46	35	19	34.2	loam
Plot 13D	Coversoil/shale	44	35	21	36.9	loam
Plot14	Coversoil/shale	42	39	19	35.4	loam
Plot 15	Coversoil/shale	38	43	19	38.2	loam
Plot 16	Shale fill	22	33	45	86.5	clay
Plot 17	Shale fill	16	39	45	114.0	silty clay
Plot 18	Shale fill	24	39	37	110.4	clay loam
Plot 19	Shale fill	26	41	33	84.4	clay loam
Plot 20	Shale fill	14	39	47	159.8	clay

Table A9. Miles City pre-treatment soil sample analyses.

Plot	Site	Mg[1] mg/L	Na[1] mg/L	Ca[1] mg/L	EC[2] (dS/m)	pH[3]	SAR[1]	NO_3-N[4] mg/kg	P[5] mg/kg	K[6] mg/kg
11	Coversoil/shale	14	474	48	2.02	9.0	15.5	16.7	4.4	316
12	Coversoil/shale	49	1410	135	5.09	8.5	26.4	21.3	3.4	148
13	Coversoil/shale	16	428	52	1.51	8.9	13.3	4.9	5.0	156
13D	Coversoil/shale	40	600	112	2.82	8.6	12.4	5.0	3.7	148
14	Coversoil/shale	11	224	31	1.02	8.9	8.8	3.3	3.0	166
15	Coversoil/shale	15	157	31	0.87	8.8	5.8	4.6	3.7	180
16	Shale fill	340	3350	452	10.10	7.8	29.0	163.6	14.3	232
17	Shale fill	94	2170	284	6.3	8.3	28.5	84.1	12.1	236
18	Shale fill	25	1340	82	4.82	8.6	33.2	78.5	6.2	202
19	Shale fill	46	1760	175	6.07	8.4	30.6	62.2	5.3	170
20	Shale fill	28	1350	91	4.89	8.3	31.8	87.5	4.4	250

[1] ASA/SSSA, 1982: Methods 10-2.3, 10-3.4 (cations analyzed by Atomic Absorption Spectrometer-AAS)
[2] ASA/SSSA, 1982: Methods 10-2.3, 10-3.3
[3] ASA/SSSA, 1982: Methods 10-2.3, 10-3.2
[4] ASA/SSSA, 1982: Methods 33-8.2, 33-8.3
[5] ASA/SSSA, 1982: Method 24-5.4
[6] ASA/SSSA, 1982: Method 9-3.1, modified (extract diluted in 0.5 % La_2O_3 with1% HCl & analyzed AAS)

Table A10. Miles City compost sample analyses.

Compost Source	pH[1]	EC[2] (dS/m)	Total C[3] (%)	Total N[4] (%)	H_2O[5] (%)	Organic Matter (%)
Rocky Mountain Compost	9.0	1.24	15.3	0.55	19.7	25.8
Earth Systems Compost	9.1	4.31	22.1	1.44	37.7	23.3

[1] TMECC method 04.11 (USDA and USCC, 2001)
[2] TMECC method 04.10 (USDA and USCC, 2001)
[3] TMECC method 04.01-A (USDA and USCC, 2001)
[4] TMECC method 04.02-D (USDA and USCC, 2001)
[5] TMECC method 03.09, ASA/SSSA 21-2.2 (1986)

APPENDIX B

Vegetation Monitoring

APPENDIX B-1

Vegetation Production Monitoring, 2005-2006

Table B-1.1. Mean biomass production data (kg/ha) from Happys Inn 2005.

Plot #	Applied Compost Depth	Amendment Method	Perennial Grass*	Non-Weedy Forb*	Weedy Forb*	Total *Live* Vegetation Production**	Litter*	Total Vegetation Production***
1	Control	No compost	18	261	0	279	0	279
2	2.5 cm compost	Incorporated	775	12	20	806	1358	2164
3	5.1 cm compost	Incorporated	1194	441	0	1635	2248	3883
4	2.5 cm compost	Blanket	475	0	0	475	2510	2985
5	5.1 cm compost	Blanket	1273	0	0	1273	1838	3111
6	Control	No compost	30	2	224	255	145	400
7	2.5 cm compost	Incorporated	239	0	35	274	217	491
8	5.1 cm compost	Incorporated	671	15	280	965	786	1751
9	2.5 cm compost	Blanket	474	0	544	1018	820	1838
10	5.1 cm compost	Blanket	936	0	1304	2239	632	2871

* Means presented are the average (kg/ha) of vegetation clipped in 5 production frames across a fixed diagonal transect.
** Total Live Vegetation Production is the sum of all vegetation from current growing season (Total Vegetation Production minus Litter).
*** Total Vegetation Production is the sum of all vegetation clipped (Grasses + Forbs + Litter).

Table B-1.2. Mean biomass production data (kg/ha) from Miles City 2006.

Plot #	Applied Compost Depth#	Amendment Method	Perennial Grass*	Annual Grass	Non-Weedy Forb*	Weedy Forb*	Total *Live* Vegetation Production**	Litter*	Total Vegetation Production***
11	2.5 cm ES compost	incorporated	6.7	535	0	924	1465	1275	2740
12	5.1 cm ES compost	incorporated	72	737	0	651	1461	1598	3059
13	5.1 cm ES compost	blanket	432	72	0	902	1406	2786	4192
14	Control	no compost	107.2	546.6	0	76	730	602	1332
15	2.5 cm ES compost	blanket	93	725	0	917	1735	1832	3567
16a	5.1 cm RM compost	incorporated	72	537	0	512	1121	2078	3199
16b	5.1 cm ES compost	incorporated	0	107	0	3558	3665	4749	8415
17a	2.5 cm RM compost	blanket	145	0	0	153	299	3319	3618
17b	2.5 cm ES compost	blanket	92	0	0	619	710	3053	3763
18a	Control	no compost	2.2	30	0	38	70	574	644
18b	Control	no compost	4.4	0	0	348	352	311	664
19a	5.1 cm RM compost	blanket	37	0	0	92	129	3006	3135
19b	5.1 cm ES compost	blanket	26	0	276	622	924	2198	3122
20a	2.5 cm RM compost	incorporated	336	0	0	0	336	1796	2132
20b	2.5 cm ES compost	incorporated	264	32	22	153	471	2426	2896

ES=Earth Systems Compost, RM=Rocky Mountain Compost
* Means presented are the average (kg/ha) of vegetation clipped in 5 production frames across a fixed diagonal transect.
** Total Live Vegetation Production is the sum of all vegetation from current growing season (Total Vegetation Production minus Litter).
*** Total Vegetation Production is the sum of all vegetation clipped (Grasses + Forbs + Litter).

APPENDIX B-2

Vegetation Cover Monitoring, 2004-2006

Table B-2.1. Vegetation cover measurements during the first growing season, 2004 at the Happys Inn test plots.

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
1	Jun-04	Control	10	99.0	1.0
2	Jun-04	1" compost incorporated	10	87.0	13.0
3	Jun-04	2" compost incorporated	10	86.0	14.0
4	Jun-04	1" compost blanket	10	52.0	48.0
5	Jun-04	2" compost blanket	10	92.0	8.0
6	Jun-04	Control	10	98.0	2.0
7	Jun-04	1" compost incorporated	10	83.0	17.0
8	Jun-04	2" compost incorporated	10	60.0	40.0
9	Jun-04	1" compost blanket	10	57.0	43.0
10	Jun-04	2" compost blanket	10	74.0	26.0

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial + Annual Grass Cover (%)	Mean Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
1	Sep-04	Control	10	0.9	1.2	0.0	0.0	97.9	2.1
2	Sep-04	1" compost incorporated	10	41.5	0.5	0.0	2.1	55.9	42.0
3	Sep-04	2" compost incorporated	10	71.9	7.7	0.0	2.0	18.4	79.6
4	Sep-04	1" compost blanket	10	95.5	0.1	0.0	3.7	0.8	95.6
5	Sep-04	2" compost blanket	10	66.1	0.0	0.0	29.8	4.1	66.1
6	Sep-04	Control	10	3.6	2.9	79.2	0.0	93.6	6.5
7	Sep-04	1" compost incorporated	10	25.7	3.2	59.1	2.6	68.6	28.9
8	Sep-04	2" compost incorporated	10	35.1	6.0	35.0	5.5	53.4	41.1
9	Sep-04	1" compost blanket	10	30.0	15.0	11.0	19.7	35.4	45.0
10	Sep-04	2" compost blanket	10	23.3	12.7	9.3	28.8	35.2	36.0

* 20x50 cm frame

Table B-2.2. Vegetation cover measurements during the second growing season, 2005 at the Happys Inn test plots.

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial Grass Cover (%)	Mean Weedy Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Compost Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
1	May-05	Control	10	2.0	0.0	0.2	1.2	0.0	96.8	2.0
2	May-05	1" compost incorporated	10	39.5	0.0	0.6	27.7	8.1	32.8	39.5
3	May-05	2" compost incorporated	10	43.5	7.3	0.0	32.0	1.5	17.2	50.8
4	May-05	1" compost blanket	10	28.2	0.1	0.0	64.6	3.9	7.1	28.3
5	May-05	2" compost blanket	10	44.9	0.0	0.2	32.3	20.4	22.8	44.9
6	May-05	Control	10	6.9	3.5	67.8	0.4	0.0	89.2	10.4
7	May-05	1" compost incorporated	10	22.7	7.3	35.6	13.2	1.6	56.8	30.0
8	May-05	2" compost incorporated	10	32.3	11.0	24.5	19.5	0.1	37.2	43.3
9	May-05	1" compost blanket	10	30.5	23.6	11.2	23.0	9.0	22.9	54.1
10	May-05	2" compost blanket	10	21.5	11.0	8.3	20.7	38.5	46.8	32.5

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial Grass Cover (%)	Mean Weedy Forb Cover (%)	Mean Non-Weedy Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Compost Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
1	Sep-05	Control	10	2.0	0.0	2.6	1.4	1.3	0.0	94.2	4.6
2	Sep-05	1" compost incorporated	10	38.0	0.5	1.8	1.1	15.5	1.5	44.2	40.3
3	Sep-05	2" compost incorporated	10	49.0	2.0	3.3	0.7	23.5	4.3	22.2	54.3
4	Sep-05	1" compost blanket	10	24.5	0.1	0.4	0.3	68.1	2.7	7.0	25.0
5	Sep-05	2" compost blanket	10	34.8	0.0	0.0	1.6	34.7	19.5	30.5	34.8
6	Sep-05	Control	10	5.2	3.5	0.6	60.0	2.4	0.0	88.4	9.3
7	Sep-05	1" compost incorporated	10	17.5	2.0	1.5	47.5	8.8	2.9	70.2	21.0
8	Sep-05	2" compost incorporated	10	31.5	11.1	4.3	24.5	15.5	2.0	37.6	46.9
9	Sep-05	1" compost blanket	10	23.8	10.8	0.0	18.8	21.0	13.2	44.4	34.6
10	Sep-05	2" compost blanket	10	18.0	12.6	0.0	13.9	11.4	41.5	58.0	30.6

* 20x50 cm frame.

Table B-2.3. Vegetation cover measurements during the third growing season, 2006 at the Happys Inn test plots.

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial Grass Cover (%)	Mean Non-Weedy Forb Cover (%)	Mean Weedy Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Compost Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
1	May-06	Control	10	1.0	0.1	0.0	2.2	2.1	0.0	96.8	1.1
2	May-06	1" compost incorporated	10	35.5	0.2	0.6	1.6	22.5	2.7	41.3	36.3
3	May-06	2" compost incorporated	10	33.0	0.7	4.8	0.7	32.5	4.9	29.0	38.5
4	May-06	1" compost blanket	10	23.5	0.0	1.2	0.6	63.2	5.2	12.2	24.7
5	May-06	2" compost blanket	10	36.5	0.0	0.0	1.0	37.5	15.9	26.0	36.5
6	May-06	Control	10	4.4	0.1	2.3	57.5	3.8	0.0	89.5	6.7
7	May-06	1" compost incorporated	10	15.7	4.5	3.2	41.5	15.5	1.0	61.1	23.4
8	May-06	2" compost incorporated	10	21.2	0.5	11.8	26.0	20.5	0.0	46.1	33.5
9	May-06	1" compost blanket	10	21.0	0.0	9.4	11.1	27.5	24.4	42.1	30.4
10	May-06	2" compost blanket	10	15.2	0.0	8.1	8.6	32.0	35.1	44.8	23.3
1	Sep-06	Control	10	0.4	0.1	0.1	0.4	0.5	0.0	98.9	0.6
2	Sep-06	1" compost incorporated	10	38.0	0.5	0.1	0.0	35.0	0.0	26.4	38.6
3	Sep-06	2" compost incorporated	10	44.5	0.0	1.6	0.0	42.0	0.0	11.9	46.1
4	Sep-06	1" compost blanket	10	30.0	2.0	0.0	0.0	53.0	10.0	15.0	32.0
5	Sep-06	2" compost blanket	10	42.5	0.0	0.0	0.0	32.5	20.5	25.0	42.5
6	Sep-06	Control	10	3.6	3.5	4.3	66.5	2.4	0.0	86.2	11.4
7	Sep-06	1" compost incorporated	10	20.0	6.5	3.2	45.5	19.5	0.0	50.8	29.7
8	Sep-06	2" compost incorporated	10	32.5	0.0	6.5	20.7	26.5	0.0	34.5	39.0
9	Sep-06	1" compost blanket	10	17.2	8.5	5.6	14.5	28.0	23.0	40.7	31.3
10	Sep-06	2" compost blanket	10	18.2	0.0	9.8	14.5	20.5	35.5	51.5	28.0

* 20x50 cm frame.

Table B-2.4. Vegetation cover measurements during the first growing season, 2004 at the Miles City test plots.

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
11	Jul-04	1" compost incorporated	10	93.1	6.9
12	Jul-04	2" compost incorporated	10	93.5	6.5
13	Jul-04	2" compost blanket	10	95.1	5.0
14	Jul-04	Control	10	88.8	11.3
15	Jul-04	1" compost blanket	10	91.9	8.1
16a	Jul-04	2" compost incorporated	10	81.4	18.6
16b	Jul-04	2" compost incorporated	10	97.4	2.6
17a	Jul-04	1" compost blanket	10	94.2	5.8
17b	Jul-04	1" compost blanket	10	87.9	12.2
18a	Jul-04	Control	10	95.6	4.4
18b	Jul-04	Control	10	96.9	3.1
19a	Jul-04	2" compost blanket	10	90.9	9.1
19b	Jul-04	2" compost blanket	10	99.4	0.6
20a	Jul-04	1" compost incorporated	10	89.8	10.3
20b	Jul-04	1" compost incorporated	10	96.0	4.1

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial + Annual Grass Cover (%)	Mean Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
11	Sep-04	1" compost incorporated	10	1.2	10.0	1.2	6.3	88.9	11.2
12	Sep-04	2" compost incorporated	10	1.3	11.3	0.5	10.0	87.5	12.6
13	Sep-04	2" compost blanket	10	2.2	29.2	0.9	15.1	68.7	31.4
14	Sep-04	Control	10	1.9	13.8	1.0	3.3	84.4	15.7
15	Sep-04	1" compost blanket	10	2.5	18.5	1.8	22.9	79.1	21.0
16a	Sep-04	2" compost incorporated	10	1.3	47.0	0.7	26.1	51.8	48.3
16b	Sep-04	2" compost incorporated	10	0.5	14.3	1.7	16.8	85.3	14.8
17a	Sep-04	1" compost blanket	10	1.1	11.5	1.1	17.5	87.4	12.6
17b	Sep-04	1" compost blanket	10	1.1	21.2	2.1	14.7	77.7	22.3
18a	Sep-04	Control	10	0.5	4.0	9.1	7.8	95.6	4.4
18b	Sep-04	Control	10	0.4	2.3	8.1	12.0	97.4	2.7
19a	Sep-04	2" compost blanket	10	1.8	16.7	1.6	16.3	81.6	18.5
19b	Sep-04	2" compost blanket	10	0.6	11.4	1.3	7.7	88.1	12.0
20a	Sep-04	1" compost incorporated	10	0.7	13.0	2.3	18.2	86.3	13.7
20b	Sep-04	1" compost incorporated	10	0.4	1.4	2.5	8.4	98.2	1.8

* 20x50 cm frame

Table B-2.5. Vegetation cover measurements during the second growing season, 2005 at the Miles City test plots.

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial Grass Cover (%)	Mean Annual Grass Cover (%)	Mean Weedy Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
11	Jun-05	1" compost incorporated	10	12.3	8.3	13.2	1.8	4.7	66.2	33.8
12	Jun-05	2" compost incorporated	10	26.5	4.6	13.6	0.8	6.3	55.3	44.7
13	Jun-05	2" compost blanket	10	20.5	17.5	11.0	2.0	4.3	51.0	49.0
14	Jun-05	Control	10	7.6	13.3	10.1	2.2	3.7	69.0	31.0
15	Jun-05	1" compost blanket	10	24.7	24.0	8.1	3.3	4.9	43.2	56.8
16a	Jun-05	2" compost incorporated	10	14.3	26.5	32.8	0.7	5.5	26.4	73.6
16b	Jun-05	2" compost incorporated	10	8.0	19.0	50.0	1.2	7.4	23.0	77.0
17a	Jun-05	1" compost blanket	10	8.6	2.0	65.0	0.7	9.4	24.4	75.6
17b	Jun-05	1" compost blanket	10	13.5	3.0	51.0	1.6	5.5	32.5	67.5
18a	Jun-05	Control	10	6.0	0.1	11.8	9.8	13.0	82.1	17.9
18b	Jun-05	Control	10	4.4	0.1	11.0	10.5	22.0	84.5	15.5
19a	Jun-05	2" compost blanket	10	20.3	1.4	42.5	0.5	4.9	35.8	64.2
19b	Jun-05	2" compost blanket	10	20.0	0.0	47.0	1.5	2.8	33.0	67.0
20a	Jun-05	1" compost incorporated	10	12.0	1.1	56.5	0.5	7.8	30.4	69.6
20b	Jun-05	1" compost incorporated	10	14.2	0.5	44.0	2.1	6.2	41.3	58.7

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial Grass Cover (%)	Mean Annual Grass Cover (%)	Mean Weedy Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Compost Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
11	Oct-05	1" compost incorporated	10	26.0	0.5	14.0	1.2	6.9	3.2	59.5	40.5
12	Oct-05	2" compost incorporated	10	35.7	1.0	12.0	0.9	6.8	4.0	51.3	48.7
13	Oct-05	2" compost blanket	10	60.5	0.2	4.1	0.7	7.0	17.7	35.2	64.8
14	Oct-05	Control	10	6.8	11.5	14.5	1.5	4.9	0.0	67.2	32.8
15	Oct-05	1" compost blanket	10	34.5	22.0	7.8	1.1	9.8	14.4	35.7	64.3
16a	Oct-05	2" compost incorporated	10	14.5	12.2	31.5	1.0	8.0	8.0	41.8	58.2
16b	Oct-05	2" compost incorporated	10	5.5	13.3	63.5	0.5	8.9	0.0	17.8	82.3
17a	Oct-05	1" compost blanket	10	9.2	0.5	67.0	1.4	5.3	4.5	23.3	76.7
17b	Oct-05	1" compost blanket	10	25.5	1.5	46.5	1.5	4.8	11.5	26.5	73.5
18a	Oct-05	Control	10	6.3	0.2	18.5	7.2	2.0	0.0	75.0	25.0
18b	Oct-05	Control	10	4.6	0.0	17.5	9.5	1.2	0.0	77.9	22.1
19a	Oct-05	2" compost blanket	10	22.0	0.0	51.5	1.4	4.5	13.5	26.5	73.5
19b	Oct-05	2" compost blanket	10	31.5	0.0	38.0	2.1	6.5	12.2	30.5	69.5
20a	Oct-05	1" compost incorporated	10	14.2	0.0	57.5	1.1	3.4	7.8	28.3	71.7
20b	Oct-05	1" compost incorporated	10	17.2	0.3	46.0	2.4	3.8	8.5	36.5	63.5

* 20x50 cm frame.

Table B-2.6. Vegetation cover measurements during the third growing season, 2006 at the Miles City test plots.

Plot Number	Sampling Date	Treatment	Number of Measurements*	Mean Perennial Grass Cover (%)	Mean Annual Grass Cover (%)	Mean Non-Weedy Forb Cover (%)	Mean Weedy Forb Cover (%)	Mean Rock Cover (%)	Mean Litter Cover (%)	Mean Compost Cover (%)	Mean Bare Ground Cover (%)	Mean Live Vegetation Cover (%)
11	may-06	1" compost incorporated	10	4.8	23.7	0.0	23.9	0.8	12.0	4.5	47.6	52.4
12	may-06	2" compost incorporated	10	14.2	22.6	0.0	18.5	0.7	16.0	3.0	44.7	55.3
13	may-06	2" compost blanket	10	28.3	8.0	0.9	2.2	1.3	35.5	6.0	60.6	39.4
14	may-06	Control	10	2.0	30.0	0.0	2.4	2.4	11.5	0.0	65.6	34.4
15	may-06	1" compost blanket	10	8.0	30.5	0.5	2.1	2.1	31.0	7.3	58.9	41.1
16a	may-06	2" compost incorporated	10	3.5	38.2	0.0	1.1	0.0	39.5	6.5	57.2	42.8
16b	may-06	2" compost incorporated	10	0.6	14.9	0.2	1.7	0.4	62.0	8.0	82.6	17.4
17a	may-06	1" compost blanket	10	4.3	2.0	0.6	2.9	0.8	62.0	18.0	90.2	9.8
17b	may-06	1" compost blanket	10	4.9	5.8	1.0	5.7	0.7	58.0	12.5	82.6	17.4
18a	may-06	Control	10	0.7	0.8	0.0	1.6	10.8	10.5	13.5	96.9	3.1
18b	may-06	Control	10	0.6	0.0	0.0	2.1	20.5	8.6	25.0	97.3	2.7
19a	may-06	2" compost blanket	10	5.2	0.3	0.0	0.6	1.1	67.0	16.2	93.9	6.1
19b	may-06	2" compost blanket	10	7.2	0.0	0.0	2.0	1.9	61.5	13.2	90.8	9.2
20a	may-06	1" compost incorporated	10	14.5	1.0	0.7	0.4	3.2	47.0	17.0	83.4	16.6
20b	may-06	1" compost incorporated	10	29.7	1.5	0.5	3.6	2.4	38.5	11.0	64.7	35.3
11	July-06	1" compost incorporated	10	2.7	28.5	2.5	16.7	0.0	18.0	0.5	49.6	50.4
12	July-06	2" compost incorporated	10	2.3	22.5	1.2	14.5	0.0	24.6	0.0	59.5	40.5
13	July-06	2" compost blanket	10	15.3	9.6	2.2	14.8	0.2	37.5	1.0	58.1	41.9
14	July-06	Control	10	3.2	20.5	0.0	2.4	0.4	18.0	0.0	73.9	26.1
15	July-06	1" compost blanket	10	2.7	18.0	2.0	15.7	0.0	37.5	0.0	61.6	38.4
16a	July-06	2" compost incorporated	10	1.4	34.5	0.0	33.9	0.0	15.9	0.0	30.2	69.8
16b	July-06	2" compost incorporated	10	0.0	12.5	0.0	48.5	0.0	31.0	0.0	39.0	61.0
17a	July-06	1" compost blanket	10	2.9	0.7	2.5	6.8	0.2	42.0	0.5	87.1	12.9
17b	July-06	1" compost blanket	10	6.2	3.2	0.0	14.0	1.3	43.5	7.0	76.6	23.4
18a	July-06	Control	10	0.9	0.7	0.0	5.5	8.3	5.3	0.0	92.9	7.1
18b	July-06	Control	10	0.3	0.0	0.0	4.1	13.7	4.7	0.0	95.6	4.4
19a	July-06	2" compost blanket	10	2.5	0.2	1.5	5.6	0.7	49.5	14.5	90.2	9.8
19b	July-06	2" compost blanket	10	1.9	0.0	0.0	14.0	0.2	45.0	20.5	84.1	15.9
20a	July-06	1" compost incorporated	10	8.6	1.0	0.0	0.1	0.7	47.5	4.0	90.3	9.7
20b	July-06	1" compost incorporated	10	11.2	2.2	0.0	7.5	1.1	34.0	4.0	79.1	20.9

* 20x50 cm frame.

APPENDIX C

Erosion Monitoring

Table C1. Happys Inn Erosion# Score measured during the monitoring period 2004-2006.

Plot	Treatment	Jun-04	Sep-04	May-05	Sep-05	May-06	Sep-06
1	Control	40	64	47	57	66	80.0
2	2.54 cm compost incorporated	28	48	29	14	6	9.0
3	5 cm compost incorporated	12	37	27	0	3	0.0
4	2.54 cm compost blanket	6	10	12	0	3	0.0
5	5 cm compost blanket	6	10	17	0	0	0.0
6	Control	0	33	46	40	29	39.0
7	2.54 cm compost incorporated	0	23	40	35	32	20.0
8	5 cm compost incorporated	0	11	34	9	31	5.0
9	2.54 cm compost blanket	0	30	42	26	28	0.0
10	5 cm compost blanket	0	25	39	28	15	0.0

Erosion scores are classified into erosion condition classes (Clark, 1980) as follows:

Score:	**Class**:
0-20	Stable
21-40	Slight
41-60	Moderate
61-80	Critical
81-100	Severe

Table C2. Miles City Erosion# Score measured during the monitoring period 2004-2006.

Plot	Treatment	Jul-04	Sep-04	Jun-05	Oct-05	May-06	Jul-06
11	2.54 cm compost incorporated	38	63	46	42	12	35.0
12	5 cm compost incorporated	40	57	44	16	9	6.0
13	5 cm compost blanket	36	24	29	7	3	11.0
14	Control	51	63	59	63	37	46.0
15	2.54 cm compost blanket	51	25	52	17	15	26.0
16a	5 cm compost incorporated	49	42	40	0	0	0.0
16b	5 cm compost incorporated	46	35	21	0	0	0.0
17a	2.54 cm compost blanket	49	40	31	0	6	28.0
17b	2.54 cm compost blanket	57	27	22	0	3	11.0
18a	Control	25	52	54	61	58	66.0
18b	Control	27	52.0	51	61	58	66.0
19a	5 cm compost blanket	53	46	32	14	9	32.0
19b	5 cm compost blanket	29	21	37	14	2	12.0
20a	2.54 cm compost incorporated	65	51	53	18	12	37.0
20b	2.54 cm compost incorporated	46	52	33	18	0	9.0

Erosion scores are classified into erosion condition classes (Clark, 1980) as follows:

Score:	**Class**:
0-20	Stable
21-40	Slight
41-60	Moderate
61-80	Critical
81-100	Severe

APPENDIX D

Photographic Monitoring

Figure D1. Photo chronology from Plot 3, glacial silt site near Happys Inn, 5 cm incorporated compost treatment from upper left to lower right: before and after construction (2003), spring and fall monitoring, 2004, 2005 and 2006.

Figure D2. Photo chronology from Plot 8, alluvial rock site near Happys Inn, 5 cm incorporated compost treatment from upper left to lower right: before and after construction (2003), spring and fall monitoring, 2004, 2005 and 2006.

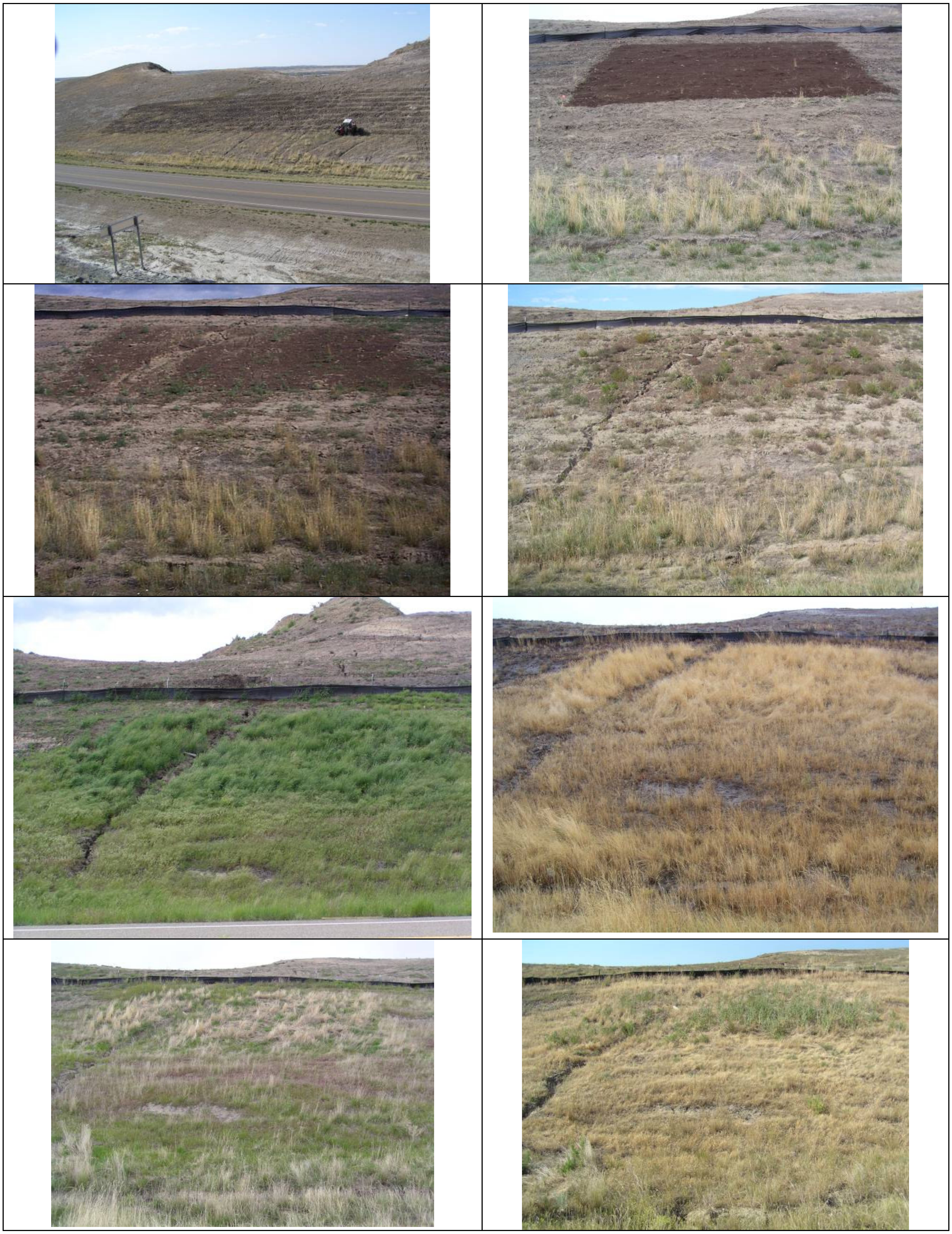


Figure D3. Photo chronology from Plot 13, thin coversoil/shale site near Miles City, 5 cm blanket compost treatment from upper left to lower right: before and after construction (2004), summer and fall monitoring 2004, spring and fall 2005, spring and summer 2006.

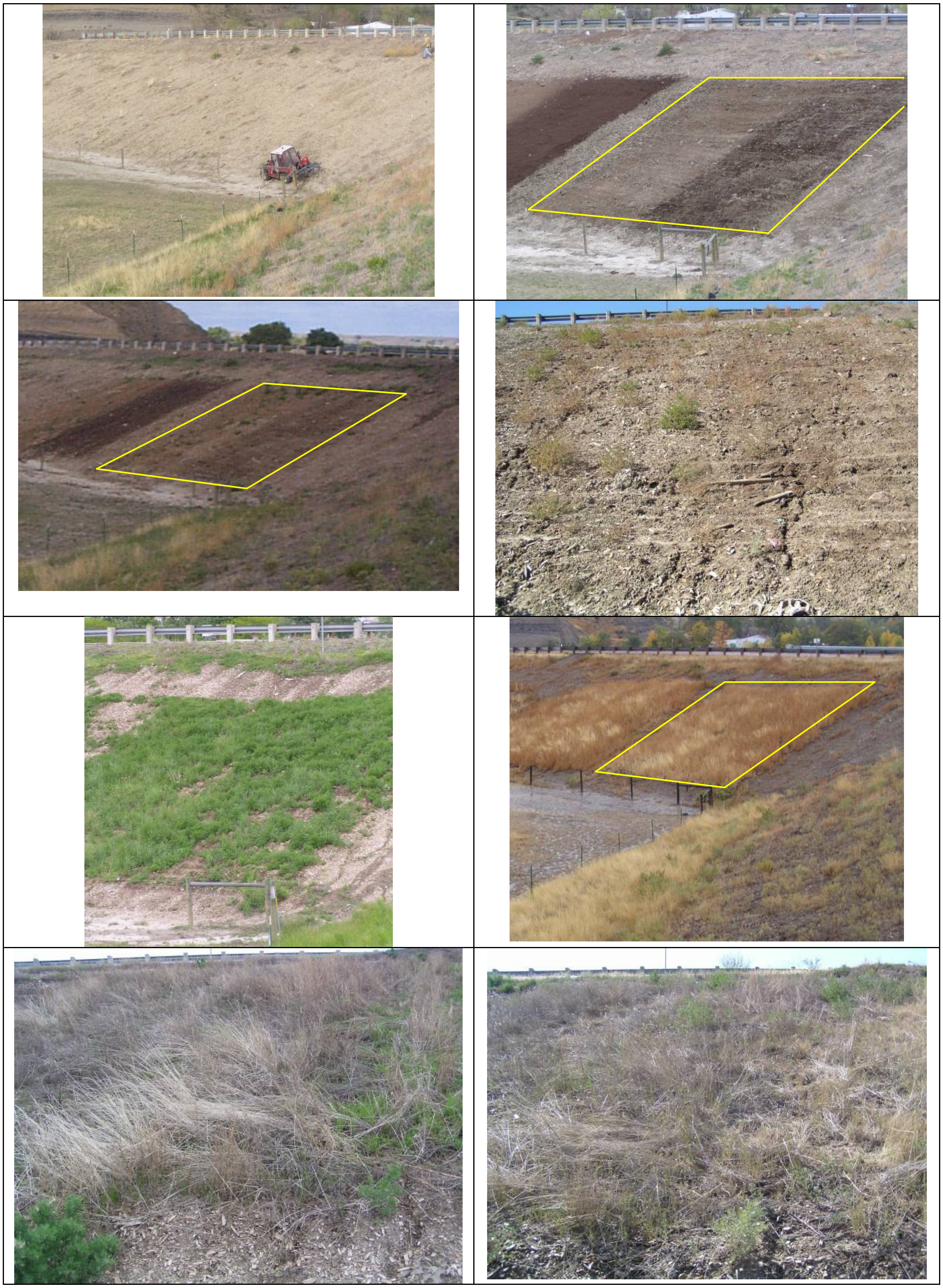


Figure D4. Photo chronology from Plot 20, shale fill site near Miles City, 2.5 cm incorporated compost treatment from upper left to lower right: before and after construction (2004), spring and fall monitoring, 2004, 2005 and 2006.

150 copies of this public document were produced at an estimated cost of $2.29 each, for a total cost of $343.67. This includes $120.84 for postage and $222.83 for printing.