NATIVE PLANT REESTABLISHMENT ON HIGHWAY CUT SLOPES USING COMPOST APPLICATION[1]

Pamela S. Blicker[2], Stuart R. Jennings and John D. Goering

Abstract. Fundamental to successful revegetation of highway corridors 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 revegetation approach is to broadcast seed and hydromulch the bare slope. These techniques frequently result in marginal plant establishment since germination and initial seedling survival is limited by nutrient poor, rocky substrates characteristic of cut slopes. Sparse vegetation establishment leads to increased erosion and sedimentation, occasional slope failure, increased noxious weed growth, and low aesthetic quality. Increased maintenance costs are often incurred in the affected areas.

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 probable optimum rates of organic compost addition to steep cut slopes, and 2) evaluation of potential equipment capable of applying and incorporating the compost to a depth of 10.1 cm (4 in.) on 2H:1V slopes. Site reconnaissance of candidate field research sites for the second phase of the project was also completed during Phase I. Phase II is still in progress and consists of two primary tasks: 1) evaluation of the efficacy of the application/incorporation equipment, and 2) measurement of vegetation condition and observations of erosional stability. This paper summarizes the findings from Phase I and work completed as of January 2006 on Phase II of the project. Additional vegetation monitoring will occur during the 2006 growing season.

Initial monitoring results suggest compost application is very effective for establishing robust vegetation communities on steep slopes under diverse climatic conditions and soil substrates.

Additional Key Words: steep slope revegetation, compost incorporation, erosion control.

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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, soil structure and soil biota. 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 are included in this list and are often exposed in road cuts. 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 often 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 (Glanvill 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 (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 probable 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.

Phase II is still in progress and consists of two primary tasks: 1) evaluation of the efficacy of the application/incorporation equipment, and 2) measurement of vegetation condition and observations of erosional stability.

This paper summarizes the findings from Phase I and work completed as of January 2006 on Phase II of the project. Additional vegetation monitoring will occur during the 2006 growing season.

Objectives

The overall research objectives for the project are to:

- Reduce sediment yield and erosion from steep highway cut slopes through amendment with compost;
- Enhance vegetation establishment on steep highway cut slopes through amendment with compost;
- Develop amendment rates, application protocols and techniques for compost addition and incorporation on steep highway cut slopes;
- Implement, monitor and evaluate test plots on steep highway cut slopes; and
- Communicate, report and provide technology transfer of the research findings.

The specific objectives of each phase are as follows.

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.

Methods

Phase I

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

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

Phase II

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.

The Montana Department of Transportation (MDT) routinely encounters all three of these types of soil materials on steep slopes during roadway construction and reconstruction. All have proven to be difficult to revegetate, leading to increased maintenance costs and increased potential for degradation of surface waters by erosion and sedimentation. Steep slope highway cuts constructed in glacial till and alluvial rock were observed in the vicinity of Happys Inn between Libby and Kalispell on U.S. Highway 2. The third material type (Fort Union Group shale) was located in a steep slope highway cut near Miles City, Montana at the junction of I-94 and U.S. Highway 12. The site conditions for the Happys Inn study areas and the Miles City study areas are described below.

Happys Inn Site Descriptions

Two sites were selected in May 2003 and are located at Mile Posts (MP) 77 (Middle Thompson Lake) and MP 69 (Loon Lake) on U.S. Highway 2, approximately 60 km east of Libby, Montana (Fig. 1).

Physiographic conditions. Both Happys Inn 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 then to the confluence with the Clark Fork River near Thompson Falls, Montana.

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.

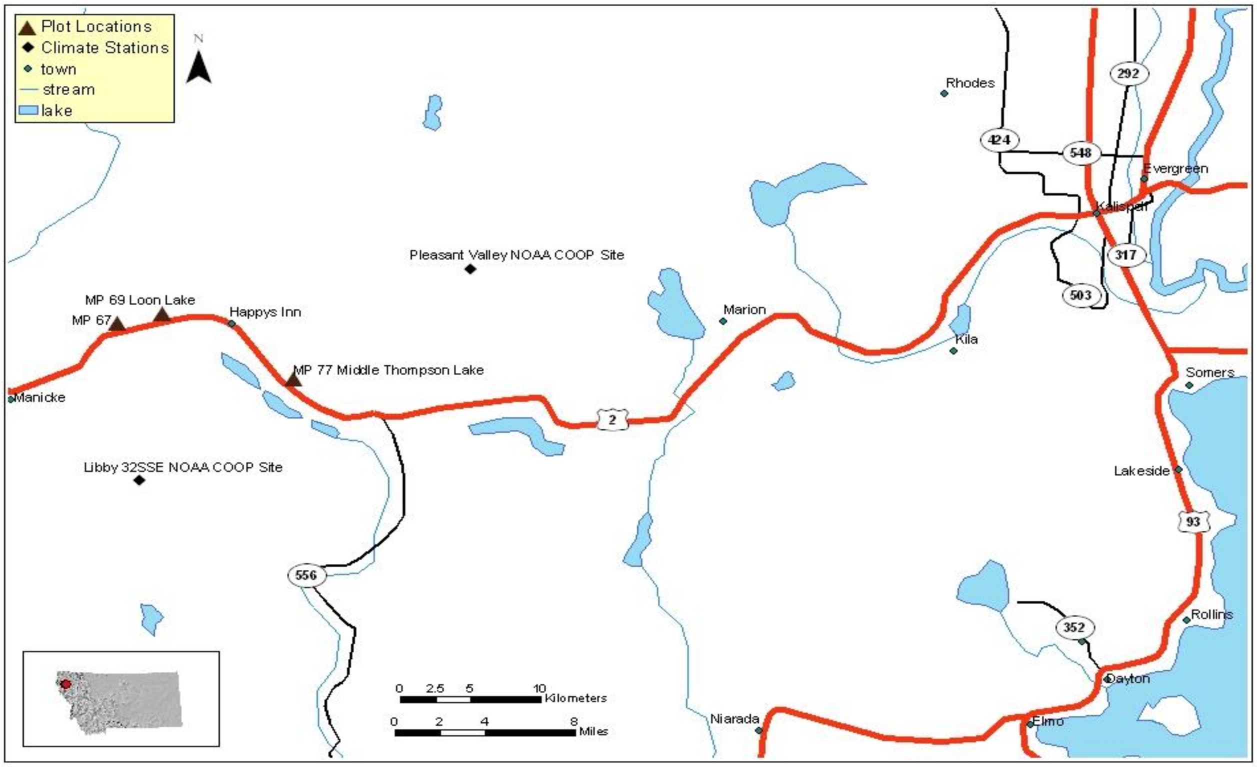

Figure 1. Happys Inn research site locations.

<u>Climatic conditions.</u> Climatic data are available from two stations near the research sites: 1) Libby 32 SSE (station 245020), and 2) Pleasant Valley (station 246576). These stations are approximately 13 km southwest and 16 to 18 km northeast of the research sites respectively (Figure 1). Elevation at both of these climatic stations is 1097 m versus approximately 1036 m 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 (Fig. 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.

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.

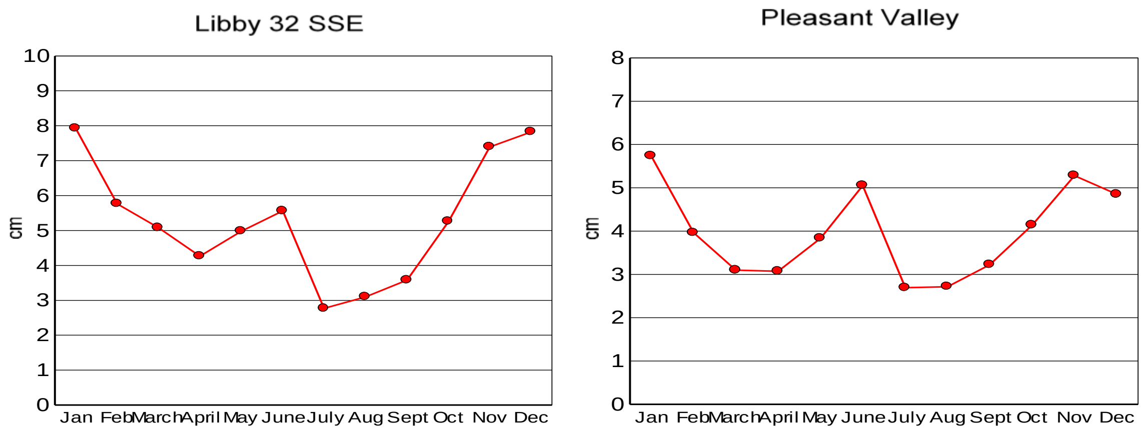

Figure 2. Monthly precipitation for NOAA stations 245020 (Libby 32 SSE) and 246576 (Pleasant Valley).

The MAPS program (Caprio et. al., 2001) was used to estimate monthly evapotranspiration. 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 respectively. Potential evapotranspiration is notably greater than mean monthly precipitation during July and August.

Happys Inn 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*), 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 constructed in 2000. Noxious weeds have begun to encroach along the margins of the sites, especially spotted knapweed *(Centaurea maculosa*). Canopy cover of vegetation at the Loon Lake site prior to implementation of the compost treatments was less than ten percent. The Middle Thompson Lake site was essentially barren of any vegetation.

Happys Inn Experimental Design. Five research plots were established at both the Loon Lake and Middle Thompson Lake sites. Two of the three types of geologic materials desired for this study are represented by these two sites (Table 1). Treatments included:

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

Happys Inn Research Plot Construction. The experimental design for this project incorporates the objectives of evaluating both the equipment used for application and incorporation of compost on steep slopes and the subsequent evaluation of the effect of the compost treatments on vegetation performance. 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 compost application was completed using a blower truck (Express Blower/Rexius Model EB-30). All tillage was performed by a modified snowcat with a 3-point mounted chisel plow.

Table 1. Plot treatments for the Loon Lake and Middle Thompson Lake research sites.

Site	Plot Number	Treatment	Mean Slope Gradient (%)	Mean Slope Length (m)	Rock Content >2mm (%, mass basis)
Middle Thompson Lake Lakebed Silt Dominated Material	1	Control, no compost, chisel plowed	34.5	18.3	1.2
	2	2.5 cm compost, incorporated with chisel plow	34.0	17.4	0.19
	3	5.1 cm compost, incorporated with chisel plowed	35.0	17.2	0.66
	4	2.5 cm compost blanket	37.0	19.8	5.11
	5	5.1 cm compost blanket	38.0	15.9	1.81
Loon Lake Coarse Textural Class Material	6	Control, no compost, chisel plowed	49.0	15.2	70.9
	7	2.5 cm compost, incorporated with chisel plow	48.5	15.2	62.6
	8	5.1 cm compost, incorporated with chisel plow	45.0	15.2	66.0
	9	2.5 cm compost blanket	43.5	15.2	47.7
	10	5.1 cm compost blanket	44.0	15.2	70.5

Middle Thompson Lake Research Site. The Middle Thompson Lake site is located along the north side of U.S. Highway 2 adjacent to Middle Thompson Lake (Figure 1). Geologic materials consist of fine textural class sediments that are assumed to be glacial lake sediments (Fig. 3). One of the primary erosion mechanisms occurring in local lakebed silt parent materials appears to be the slumping of saturated surface layers that overlie frozen substrate during spring thaw cycles.

Figure 3. Research Plot 1 at the Middle Thompson Lake site prior to plot implementation. Note accumulated sediment in ditch, rills, and the general lack of vegetation cover.

Research plots at this site are 12.2 m wide with lengths ranging from 17.2 to 19.8 m. All buffer strips are 3 m except that between plots 2 and 3 that is 9.1 m wide (Fig. 4). 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.

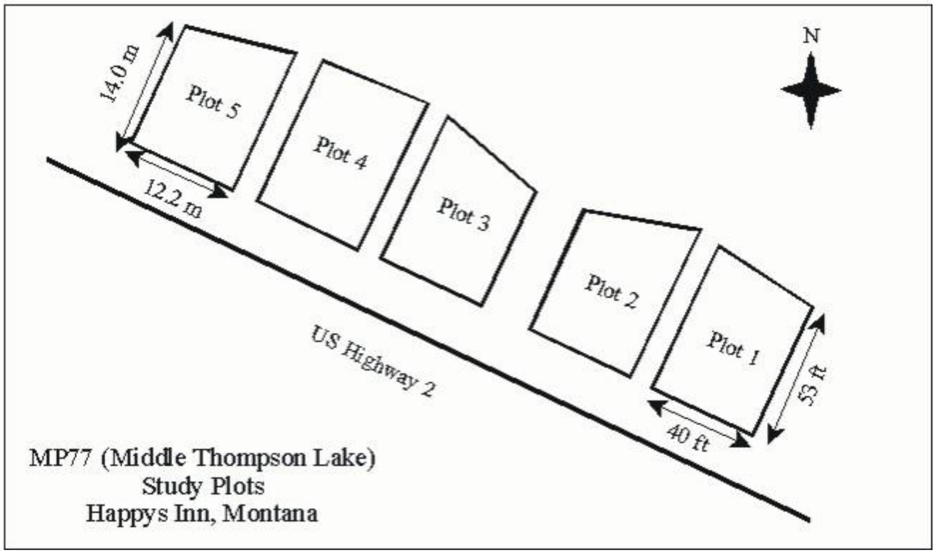

Figure 4. Plot layout at the Middle Thompson Lake research site.

<u>Loon Lake Research Site.</u> The Loon Lake site is located on the north side of U.S. Highway 2 immediately northwest of Loon Lake (Figure 1). The site is characterized by very coarse textural class material with abundant boulders and cobbles (Figure 5). Mean rock content (> 2 mm) was 63.5 percent (Table 1). All plots at this site were 15.24 m square (232.2 m^2) with 3 m buffer zones between plots (Fig. 6).

Figure 5. Loon Lake research area preconstruction conditions, Plot 8.

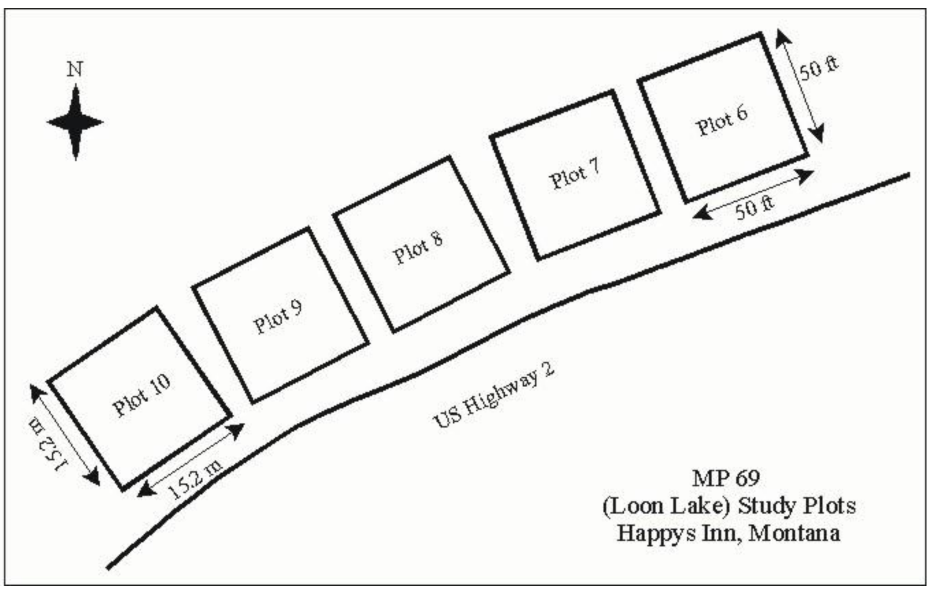

Figure 6. Research plot layouts at the Loon Lake site.

Compost was applied at this site on October 21, 2003. Seed was broadcast at a rate of 39 kg/ha. Plots 7 and 9 received 2.5 cm compost blankets while plots 8 and 10 received 5.1 cm blankets. Plots 6, 7 and 8 were chisel plowed on October 23, 2003.

Happys Inn Plot Seeding. All plots at both Loon Lake and Middle Thompson Lake were seeded with the same seed mix (Table 2), which was obtained from Bruce Seed Farm, Inc. Seed was applied using a hand operated broadcast seeder at a total rate of 0.91 kg per plot. The seed rate was approximately 39 kg/ha. Seed was applied in two applications, the first on bare substrate and the second following application of 1.3 cm 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 of seed was specifically applied to plot 7 at Loon Lake 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.

Happys Inn 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 Middle Thompson Lake 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. Compost incorporation on the coarse textured materials at Loon Lake 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. 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 2. Seed mix species used at the Loon Lake and Middle Thompson Lake research sites.

Species	Common Name[1]	Variety	Percent of Mix (*pure live seed* weight basis)
Elymus trachycaulus ssp. trachycaulus	Slender Wheatgrass	Pryor	7.62
Elymus hoffmanii	Hybrid Wheatgrass	Newhy R/S	20.65
Elymus canadensis	Canada Wildrye	V.N.S.	12.70
Bromus marginatus	Mountain Brome	Bromar	12.18
Pseudoroegneria spicata ssp. spicata	Bluebunch Wheatgrass	Goldar	12.70
Poa ampla	Big Bluegrass	Sherman	2.66
Nassella viridula	Green Needlegrass	Lodorm	7.38
Elymus lanceolatus ssp. psammophilus	Streambank Wheatgrass	Sodar	12.85
Festuca ovina	Sheep Fescue	Covar	2.61
Festuca arundinacea	Tall Fescue	Fawn	5.1

[1] Seed label reported only common name and variety.

Happys Inn Compost Application and Incorporation Equipment Evaluation.

The equipment evaluated at Happys Inn included:

1. Express Blower (Rexius) blower truck model EB-30;

2. LMC model 3700C snowcat using Pisten Bully 2.5 m wide steel tracks and a standard agricultural 3-point quick attach hitch; and

3. A 2.5 m wide 3-point mounted, spring shanked Graham Hoeme chisel plow.

The performance evaluation of this equipment, along with one demonstration unit (Land Tamer) was conducted during construction of the test plots. The Rexius blower truck was used to apply compost the compost to the surface of the test plots. The snowcat (modified LMC 3700C) and chisel plow (Grahm Hoeme) were evaluated for their ability to incorporate the compost on a steep slope. The Land Tamer was demonstrated at the Loon Lake site but was not used for compost incorporation. Performance of reclamation equipment used is discussed in the Results section.

Miles City Site Description

The Miles City sites were selected March 2004 and are located at the junction of I-94 and U.S. Highway 12, approximately 4.8 km (3 miles) east of Miles City, Montana (Fig. 7).

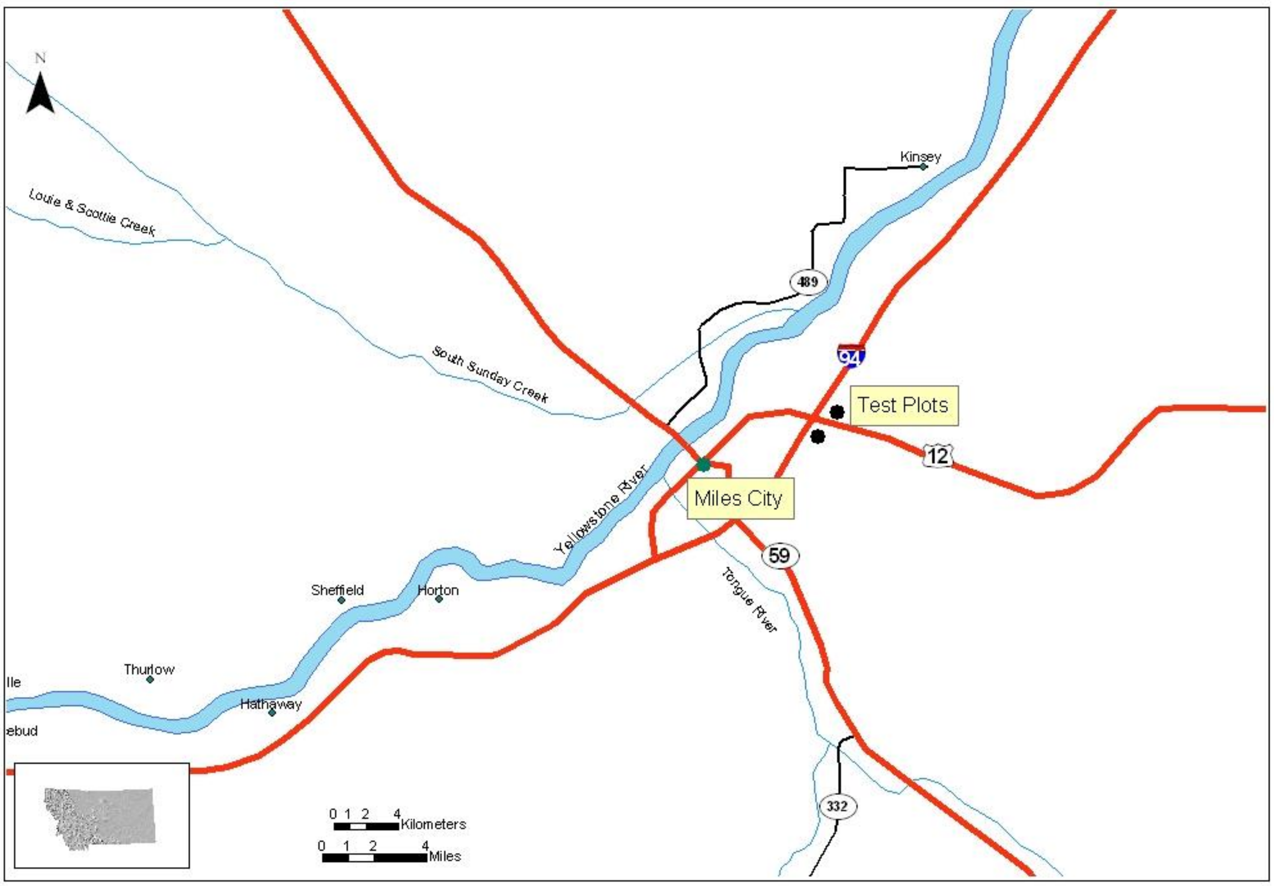

Figure 7. Miles City research area location.

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, 4.8 km (3 miles) west of the research area, to about 975.4 m (3200 feet) in the Government Hill area about 9.6 km (6 miles) 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 15.2 m (50 ft) wide composed of brownish yellow, cross-bedded sandstone. Thickness of member 45.7 m (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) angular boulders on the plots. A thin veneer of low-quality coversoil 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. Shale fragments with little weathering evident dominate the surface of this area.

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 and 6.3 km southwest of the research sites respectively (Figure 7). Elevations at these stations (719.3 and 799.8 m, 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) likely due to the 80.5 m elevation difference between the stations (Fig. 8). 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. 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.

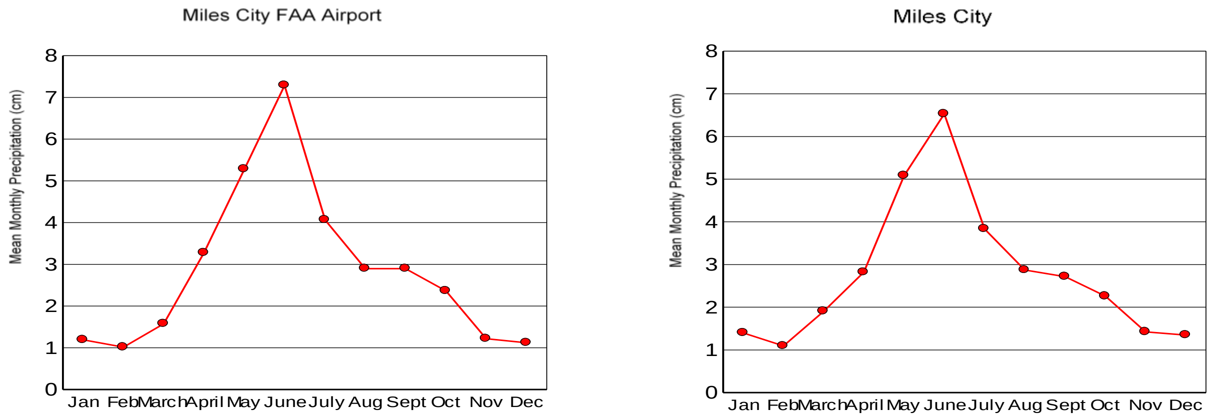

Figure 8. Monthly precipitation for NOAA stations 245690 (Miles City FAA Airport) and 245685 (Miles City).

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.

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 (solar unit method) exceeds precipitation during this period (24.8 cm) by nearly 300 percent. The month of July exhibits the greatest PET (20 cm) indicating a potential deficit of nearly 16 cm between available precipitation and PET. While the bulk of the annual precipitation occurs during the growing season, adequate precipitation is clearly the primary limiting factor for vegetation production at this site.

Miles City Existing Vegetation. Vegetation cover was very poor at the coversoiled cut slope site and the I-94 off ramp site was essentially void of vegetation.

Miles City Experimental Design

Ten research plots were established at the Miles City research area (Figure 7). 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, and
- Vendor equipment breakdown prevented delivery of the entire required compost volume requiring acquisition of additional compost from a second vendor.

The coversoiled cut slope 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. The I-94 off-ramp fill was composed of raw shale with very poor 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.

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. Arrangements were made for the blower truck to load an additional 13 m^3 (17 cy) of 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 9). 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 3).

<u>Miles City Research Plot Construction - Plots 11 Through 15</u>

Five plots were constructed on the south aspect cut slope on U.S. Highway 12 immediately east of the eastbound off ramp from Interstate Highway 94 at Mile Post 141. 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. The centers of each plot were located and composite soil samples collected prior to construction. Following sample collection, all plots were tilled across the slope.

Figure 9. 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)

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, 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 5.1 cm 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 3). A silt fence was installed the entire length of the site (88.4 m) up-slope from the top of the plots to control run-on sedimentation from areas above the research plots.

Table 3. Plot treatments for the Miles City research sites.

Site	**Plot Number**	**Treatment**	**Mean Slope Gradient (%)**	**Mean Slope Length (m)**	**Rock Content > 2mm (%, mass basis)**
Miles City Cut Slope Shale Dominated Material with approximately 5 cm loam/sandy loam coversoil applied	11	2.5 cm compost, incorporated with chisel tipped tiller	30.5	12.2	0.93
	12	5.1 cm compost, incorporated with chisel tipped tiller (no compost on east ½ plot)	32.0	12.2	4.04
	13	5.1 cm compost blanket	33.5	12.2	1.98
	14	Control, no compost, chisel plowed	33.5	12.2	1.45
	15	2.5 cm compost blanket	33.5	12.2	0.92
Miles City Fill Slope Shale Fragment Fill	16	5.1 cm compost, incorporated with chisel tipped tiller	30	15.2	17.45
	17	2.5 cm compost blanket	33.5	15.2	44.06
	18	Control, no compost, chisel tipped tiller	36.5	15.2	16.48
	19	5.1 cm compost blanket	37.5	15.2	27.03
	20	2.5 cm compost, incorporated with chisel plow	39.5	15.2	64.65

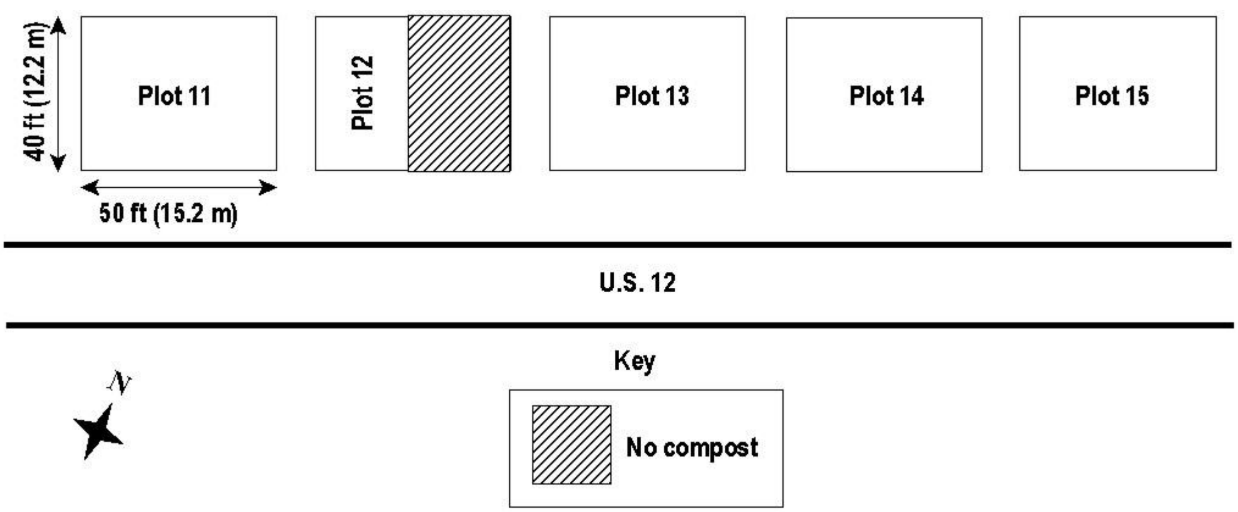

Figure 10. Research plot layouts at the U.S. Highway 12 cut slope site.

Miles City Plot Construction - Plots 16 through 20

Research plots 16 through 20 were 12.2 m (40 ft) wide with a slope length of 15.2 m (50 ft) (Figure 11). 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 3). 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.

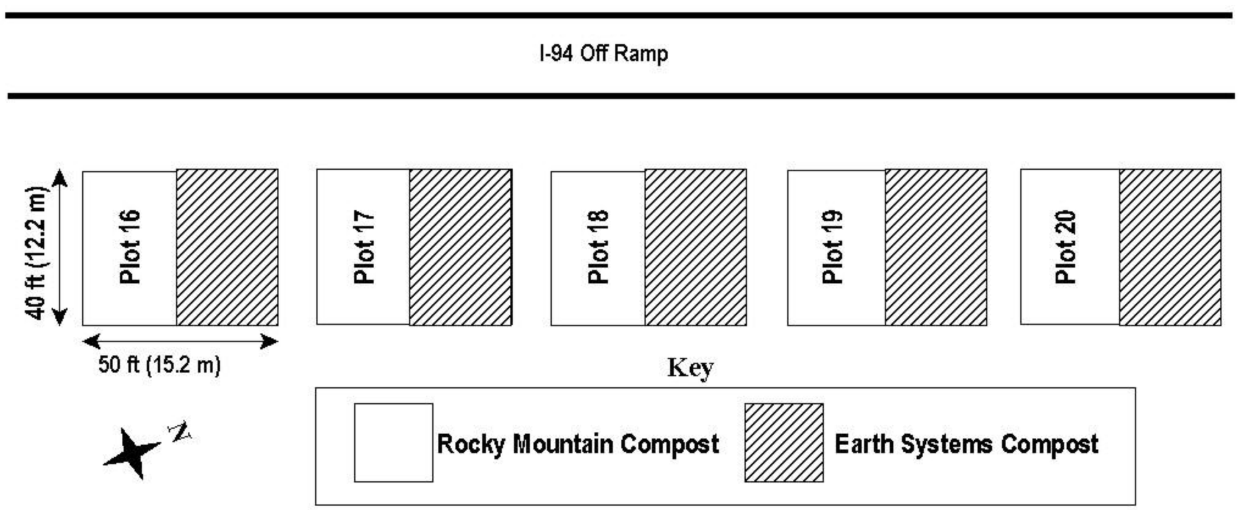

Figure 11. Research plot layouts at the I-94 fill slope site.

Miles City Seeding. All plots at both Miles City sites were seeded with the same seed mix (Table 4) that was obtained from Bruce Seed Farm, Inc. Seed was applied using a hand operated broadcast seeder at a total rate of 1.81 kg per plot. The seed rate is approximately 97 kg/ha. Seeding methodology was identical to that used at the previously constructed Happys Inn sites. 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.

Compost Mixing. Compost was mixed into the appropriate test plots using an AEBI TT88 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 10cm (4 inches) of the soil. An initial tillage pass was made pulling the chisel 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.

Table 4. Seed mix species used at the Miles City research sites.

Species	Common Name[1]	Variety	Percent of Mix (*pure live seed* basis)
Elymus trachycaulus ssp. trachycaulus	Slender Wheatgrass	Pryor	12.31
Elymus hoffmanii	Hybrid Wheatgrass	Newhy R/S	18.10
Pascopyrum smithii	Western Wheatgrass	Rosana	18.77
Leymus triticoides	Wildrye, Beardless	Shoshone	17.92
Sporobolus airoides	Alkali Sacaton	V.N.S.	6.43
Cleome serrulata	Bee Plant, Rocky Mountain	V.N.S.	12.07
Astragalus cicer	Cicer Milkvetch	Lutana	6.64
Ericameria nauseosa ssp. nauseosa	Rubber Rabbitbrush		2.50
Sarcobatus vermiculatus	Black Greasewood		2.50

[1] Seed label contained only common name and variety.

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.

Miles City Compost Application and Incorporation Equipment Evaluation

The equipment utilized for this part of the study included:

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

The blower truck used for compost application for the Miles City plot construction was the same unit used for the Happys Inn sites. An AEBI Terratrac TT88 Steep Terrain Tractor and a Ford Spring Shanked Tiller were evaluated for compost incorporation on steep slopes. The AEBI tractor employed for this work was rented from the Bridger Bowl Ski Area near Bozeman, Montana where its main use is mowing ski runs. The Ford tiller was attached to the AEBI Tractor for the purposes of evaluating the incorporation of compost.

Sampling and Analysis

Primary experimental response variables evaluated in this study were vegetation, soil and erosion. Vegetation and erosional conditions were measured over the first 2 growing seasons and will be measured again in June and September of 2006. Soil sampling occurred prior to and following plot construction to establish the physical and chemical characteristics of the research plots before and after construction.

Monitoring

Soil sampling. 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 5). These data establish the pretreatment soil condition and a point of comparison following two years of plant growth.

Happys Inn Compost Sampling. 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 6.

Table 5. 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] American Society of Agronomy, Soil Science Society of America, 1982.
[2] American Society of Agronomy, Soil Science Society of America, 1986.

Miles City Compost Sampling. 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 6.

Table 6. 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, 200

Vegetation Monitoring. Vegetation monitoring occurred in Spring and Fall of 2004 and 2005 and will occur again in Spring and Fall of 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 Daubenmire (Daubenmire 1968) frame 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 25 x 25 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.

Erosion Response Variables. 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 will also be monitored during 2006. Data collected from vegetation monitoring and from plot soil sample information will be used with the Revised Universal Soil Loss Equation (RUSLE) program to calculate sediment yields for each plot on an annual basis. All RUSLE program inputs except climatic data will be available from site sampling and monitoring data. Climate data will be extracted from NRCS or NOAA databases best suited to the experimental locations. RUSLE calculations and summary will be contained in the final report scheduled for completion in December of 2006.

Results

Compost Application and Incorporation Equipment Evaluation

Happys Inn The equipment evaluated at Happys Inn included:

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

Blower Truck. The blower truck experienced no difficulties applying compost to the research plots (Fig. 12). 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 on uneven ground 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 compost layer on each plot and an additional 15 to 20 minutes to apply the remaining 3.8 cm of compost on the 5.1 cm treatments for an approximate rate of 0.05 ha/hr (Table 7). 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 5.1 cm compost blanket would be applied at 0.18 ha/hr.

Figure 12**.** Express Blower Model EB-30 applying compost at the Middle Thompson Lake site.

Table 7. 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

Snowcat. The snowcat utilized for this project was a modified LMC 3700C (Fig. 13). 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; Solid rubber boggy wheels; 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 13. Modified LMC 3700C initiating tillage on plot 8, Loon Lake 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 Middle Thompson Lake. 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 Loon Lake 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 Loon Lake 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.

Chisel Plow. The Graham Hoeme chisel plow utilized for this study worked equally well in both coarse and fine textural classes of material (Fig. 14). 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 Middle Thompson Lake site.

Figure 14. Graham Hoeme 2.4 m (8 ft) spring shanked chisel plow at Loon Lake.

Land Tamer. PFM Manufacturing provided a standard industrial LT model for demonstration purposes at the Loon Lake site (Fig. 15). 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 Loon Lake, 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 Middle Thompson Lake 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 15. Land Tamer industrial model LT adjacent to Loon Lake research site.

Miles City Equipment Evaluation. The equipment utilized for this part of the study included:

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

Blower Truck. The blower truck utilized for the Miles City plot construction was the same unit used for the Happys Inn sites. 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.

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 (Fig. 16). The Phase I report for this research project identified the AEBI tractors as good candidates for compost incorporation on steep cut slopes. The TT88 used shares the dual 3-point system and dual PTOs (front and back) common to most Terratrac models, had an 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.

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 Loon Lake 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 or down slopes.

Figure 16. AEBI Terratrac TT88 .

Ford Spring Shanked Tiller. The Ford tiller used for this work had 9 shanks mounted at 0.30 m (1 foot) centers (Fig. 17). 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 cm (4 inch) tillage depth and was capable sinking the shanks 0.3 m (1 foot), especially when tilling down slope.

Figure 17. Ford spring-shanked tiller on Plot 20 (Rocky Mountain compost in foreground, Earth Systems material in background).

<u>Soil Evaluation.</u>

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 8 and 9.

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. Replicated experimental plots were not constructed. Inferences between individual plots are not backed up with statistical comparisons derived from 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% 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.

Table 8. Soil Analytical Results for Happys Inn and Miles City - Pre-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 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
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	9	2020	15.5	2.36	16.7	4.4	316	14	474	48
Plot-12	8.5	5090	26.4	1.9	21.3	3.4	148	49	1410	135
Plot-13	8.9	1510	13.3	1.72	4.9	5	156	16	428	52
Plot-14	8.9	1020	8.8	1.83	3.3	3	166	11	224	31
Plot-15	8.8	870	5.8	1.71	4.6	3.7	180	15	157	31
Plot-16	7.8	10100	29	8.56	163.6	14.3	232	340	3350	452
Plot-17	8.3	6300	28.5	3.45	84.4	12.1	236	94	2170	284
Plot-18	8.6	4820	33.2	2.08	78.5	6.2	202	25	1340	82
Plot-19	8.4	6070	30.6	2.43	62.2	5.3	170	46	1760	175
Plot-20	8.3	4890	31.8	1.82	87.5	4.4	250	28	1350	91

Less clear trends in fertility, organic matter levels and SAR were observed at the Miles City plots. 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. The unexplained variability in pre-treatment soil OM and fertility levels is evident in Table 8 which reports the pre-treatment soil conditions. At the Miles City plots, the treatment effect of compost is not well defined by soil analysis.

Table 9. Soil Analytical Results for Happys Inn and Miles City - Post-treatment.

Sample ID	pH	EC(uS)	SAR	OM	NO_3-N mg/kg	P mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg
Happys Inn Middle Thompson Lake – 2005 After Treatment									
Plot-1	8.45	880	10.6	0.16	0.7	3.7	7.5	176	8.7
Plot-2	7.86	1021	2.9	2.62	1.0	81.2	46.1	118	51.6
Plot-3	7.29	1654	0.5	5.31	1.4	156	126	33.7	160
Plot-4	7.19	1277	0.5	10.6	1.7	182	81.5	26.9	97.6
Plot-5	7.23	1353	0.4	11.2	2.8	256	87.8	21.4	105
Happy' s Inn Loon Lake – 2005 After Treatment									
Sample ID	pH	EC(uS)	SAR	OM	NO_3-N mg/kg	P mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg
Plot-6	7.84	366	0.6	0.72	0.9	8.9	7.9	17.1	48.6
Plot-7	7.73	950	0.4	4.52	1.6	73.8	40.4	19.6	137
Plot-8	7.79	836	0.3	6.7	1.7	125	39.7	13.7	121
Plot-9	7.86	761	0.3	7.55	0.8	103	35.3	14.3	92.1
Plot-10	7.51	836	0.3	13.2	3.7	212	46.0	16.1	90.4
Miles City – 2005 After Treatment									
Sample ID	pH	EC(uS)	SAR	OM	NO_3-N mg/kg	P mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg
Plot-11	8.83	4980	19.7	5.41	42.2	175	40.0	1000	128
Plot-12	8.77	7090	24.0	4.49	35.8	124	63.0	1470	181
Plot-13	8.54	3105	7.1	4.40	21.5	114	42.0	341	107
Plot-14	8.01	9720	15.9	3.37	10.7	8.5	267	1760	492
Plot-15	8.43	1939	4.7	3.52	22.4	83.6	24.3	179	69.6
Plot-16A	8.36	5270	1.7	10.6	20.8	67.8	61.0	108	193
Plot-16B	8.71	5610	18.1	11.5	54.5	271	57.0	1070	169
Plot-17A	8.97	6800	28.4	7.21	29.0	24.4	47.0	1530	141
Plot-17B	8.95	6870	27.7	7.4	54.9	169	51.0	1630	178
Plot-18A	8.66	7330	27.4	3.17	43.6	7.9	48.0	1560	167
Plot-18B	8.98	5290	35.4	2.02	23.8	5.8	16.1	1220	63.1
Plot-19A	8.84	4980	25.0	5.53	27.0	36.3	27.9	1070	92.3
Plot-19B	8.82	4840	24.5	10.8	64.9	254	29.4	1070	96.3
Plot-20A	8.84	5370	25.9	4.19	9.0	25.4	27.8	1140	101
Plot-20B	8.86	5780	28.5	4.56	21.1	101	28.7	1350	122

Compost Evaluation

The chemical characteristics of compost used in Happys Inn and Miles City research plots are exhibited in Table 10.

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.

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),
- Higher total carbon (22.1 versus 15.3 percent),

- Higher total nitrogen (1.44 versus 0.55 percent, and
- 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.

Table 10. Chemical Characteristics of Compost used to Construct 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

<u>Vegetation Monitoring</u>

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 (Fig. 18 and 19). Tables 11 shows the average canopy cover of selected attributes measured in October 2005 at the Happys Inn sites. Vegetation 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. Table 12 shows the average canopy cover of selected attributes at the Miles City Research sites.

Figure 18. Happys Inn Plots, Spring 2005

Figure 19. Mile's City I-94 Off Ramp Plots, Spring 2005

Table 11. Mean Vegetation Cover measured at the Happys Inn Research Sites, October 2005**.**

Plot #	Applied compost Depth	Amendment Method	Grasses*	Forbs*	Spotted Knapweed*	Litter*
Middle Thompson (Lacustrine silt parent material)						
1	Control - no compost	none	2.0	2.6	0.0	1.3
2	2.5 cm compost	incorporated	38.0	1.8	0.5	15.5
3	5.1 cm compost	incorporated	49.0	3.3	2.0	23.5
4	2.5 cm compost	blanket	24.5	0.4	0.1	68.1
5	5.1 cm compost	blanket	34.8	0.0	0.0	37.8
Loon Lake (Alluvial rock parent material)						
6	Control - no compost	none	5.2	0.6	3.5	2.6
7	2.5 cm compost	incorporated	17.5	1.5	2.0	8.8
8	5.1 cm compost	incorporated	31.5	4.3	11.1	15.5
9	2.5 cm compost	blanket	23.8	0.0	10.8	21.0
10	5.1 cm compost	blanket	20.0	0.0	12.6	11.4

* Means presented are the average of 10 cover frames taken across a fixed diagonal transect.

It is apparent that all plots with compost addition, whether it was a blanket or incorporated, had markedly higher vegetation cover than the control plots. At the Happys Inn sites, cover of perennial grasses was highest on plots where compost was incorporated into the existing geological material. However, it should be noted that a thick layer of vegetative litter covered the surface of the 2.5 cm compost blanket plots at the Middle Thompson Lake site. This litter was due to very robust growth during the first growing season and may have contributed to the lower cover in year two on the blanketed plots.

Spotted knapweed (*Centaurea maculosa*) was invading the upper portions of the plots 8, 9, and 10 at the Loon Lake Research site. These weeds are migrating from a heavy knapweed infestation located less than 6 m upslope of these plots. The Montana Department of Transportation has been 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.

Table 12. Mean Vegetation Cover measured at the Miles City Plots, October 2005.

Miles City Plots						
Plot #	**Applied Compost Depth**	**Amendment Method**	**Perennial Grass***	**Annual Grass***	**Weedy Forbs***	**Litter***
11	2.5 cm compost	incorporated	26.0	0.5	14.0	6.9
12	5.1 cm compost	incorporated	35.7	1.0	12.0	6.8
13	5.1 cm compost	blanket	60.5	0.2	4.1	7.0
14	Control - no compost	none	6.8	11.5	14.5	4.9
15	2.5 cm compost	blanket	34.5	22.0	7.8	9.8
16a	5.1 cm compost	incorporated	14.5	12.2	31.5	8.0
16b	5.1 cm compost	incorporated	5.5	13.3	63.5	8.9
17a	2.5 cm compost	incorporated	9.2	0.5	67.0	5.3
17b	2.5 cm compost	incorporated	25.5	1.5	46.5	4.8
18a	Control - no compost	none	6.3	0.2	18.5	2.0
18b	Control - no compost	none	4.6	0.0	17.5	1.2
19a	5.1 cm compost	blanket	22.0	0.0	51.5	4.5
19b	5.1 cm compost	blanket	31.5	0.0	38.0	6.5
20a	2.5 cm compost	blanket	14.2	0.0	57.5	3.4
20b	5.1 cm compost	blanket	17.2	0.3	46.0	3.8

* Means presented are the average of 10 cover frames taken across a fixed diagonal transect.

Miles City plots with compost addition had markedly higher vegetation cover than the control plots. Plots with 5.1 cm compost blanket had the highest canopy cover during the September 2005 sampling event. This could be a result of the blanket helping to retain soil moisture during the drought conditions. 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. At this time in the study it is difficult to ascertain the reason for the difference in the grass cover on plots 17a and 17b. Otherwise, there did not appear to be a considerable difference between the two types of compost and plant establishment in the second growing season.

Annual weeds were significant at the some of the Miles City plots. This is most likely due to the 2004 drought conditions and the slow start of the perennial grasses seeded at the site. The surrounding area, most notably along the highway corridor, is weedy and likely serves at a conduit for weed seed distribution. It is anticipated that because the perennial grasses became well established during the second growing season, cover of annual weeds will decrease.

Production data were collected at the Happys Inn sites in October 2005, the averages for each plot are shown below in Table 13.

Production

Production measurements were only collected at the Happys Inn research plots. Drought conditions at Miles City during the first growing season limited plant development. At the Happys Inn research plots, above ground biomass production of desirable species was greater on all compost treated plots as compared to the control plots. Plant litter accumulated from vigorous plant growth during the first growing season and was significant on Happys Inn plots 2 through 5, which may have impacted growth of the 2005 vegetation on these plots. Additionally, the presence of weedy forbs in Happys Inn plots 8 through 10 most likely contributed to a decrease in the production of perennial grasses and non-weedy forbs in these plots. Overall, the robust above ground biomass production measured on Happys Inn treated plots can be directly attributed to compost addition to native parent material.

Table 13. Production data (kg/ha) from Happys Inn 2005.

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

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

<u>Erosion</u>

Erosion on all plots was qualitatively evaluated during each site visit. Results from all of the erosion evaluations from June 2004 through the September 2005 at Happys Inn are shown in Table 14 and the results from erosion evaluation at Miles City are shown in Table 15. Higher "scores" for the erosion evaluation indicate more severe erosion conditions.

Sediment movement observed on treated plots with good vegetation development exhibits less susceptibility to erosion compared to the controls where limited vegetation. During 2005 all plots treated with compost demonstrated less erosion that the adjacent controls. This trend was exhibited at both Happys Inn and Colstrip on all 4 parent materials.

Table 14. Erosion Condition at Happys Inn Research Plots - September 2005.

Plot #	Applied Compost Depth	Amendment Method	Material	Score# June 2004	Score# Sept. 2004	Score# June 2005	Score# Sept. 2005
1	Control	no compost	Lacustrine silt	40	64	47	57
2	2.5 cm compost	incorporated	Lacustrine silt	28	48	29	14
3	5.1 cm compost	incorporated	Lacustrine silt	12	37	27	0
4	2.5 cm compost	blanket	Lacustrine silt	6	10	12	0
5	5.1 cm compost	blanket	Lacustrine silt	6	10	17	0
6	Control	no compost	Alluvial rock	0	33	46	40
7	2.5 cm compost	incorporated	Alluvial rock	0	23	40	35
8	5.1 cm compost	incorporated	Alluvial rock	0	11	34	9
9	2.5 cm compost	blanket	Alluvial rock	0	30	42	26
10	5.1 cm compost	blanket	Alluvial rock	0	25	39	28

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

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

Table 15. Erosion Condition at Miles City Research Plots - October 2005.

Plot #	Applied Compost Depth	Amendment Method	Material	Score# July 2004	Score# Sept. 2004	Score# June 2005	Score# Oct. 2005
11	2.5 cm compost	incorporated	Shale	38	63	46	42
12	5.1 cm compost	incorporated	Shale	40	57	44	16
13	5.1 cm compost	blanket	Shale	36	24	29	7
14	Control	no compost	Shale	51	63	59	63
15	2.5 cm compost	blanket	Shale	51	25	52	17
16a	5.1 cm compost	incorporated	Shale Fragment Fill	59	42	40	0
16b	5.1 cm compost	incorporated	Shale Fragment Fill	46	35	21	0
17a	2.5 cm compost	incorporated	Shale Fragment Fill	49	40	31	0
17b	2.5 cm compost	incorporated	Shale Fragment Fill	57	27	22	0
18a	Control	no compost	Shale Fragment Fill	25	52	54	61
18b	Control	no compost	Shale Fragment Fill	27	52	51	61
19a	5.1 cm compost	blanket	Shale Fragment Fill	53	46	32	14
19b	5.1 cm compost	blanket	Shale Fragment Fill	29	21	37	14
20a	2.5 cm compost	blanket	Shale Fragment Fill	65	51	53	18
20b	2.5 cm compost	blanket	Shale Fragment Fill	46	52	33	18

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

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

The Happys Inn plots constructed on glacial silt 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 while the untreated control exhibited 'critical' erosion. Geological materials impart a strong influence on erosion where road construction occurs in glacial till with poor infiltration characteristics. Stormwater runoff is a common consequence of slopes without stabilizing vegetation. The compost treatment was sufficient to allow establishment of adequate vegetation cover to protect the soil surface and mitigate erosion. The alluvial rock research plots exhibited less distinct trends. The compost treated plots generally exhibited either 'slight' or 'stable' erosional condition while the untreated control exhibited 'slight' to 'moderate' amounts of erosion.

The Miles City plots that had compost incorporated into the surface material were stable with the exception of plot 11 (1 inch compost depth), which exhibited moderate amounts of erosion. The compost blanketed plots 13, 15, 19 and 20, were stable.

Discussion

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 a 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 of hose and likely considerable farther. 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. Pisten Bully introduced a new "dry ground" model in 2003. This is the Pisten Bully 100 Flexmobil that does include an advanced suspension. Although this machine is less powerful than the modified LMC 3700C used in this study, it may be better adapted to conditions such as found at Loon Lake.

Miles City Equipment Performance Summary.

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

Soil Conditions.

The pre-treatment and post-treatment soil chemical data suggest (Table 8) 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. Unfavorably 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 has higher mean SAR (30.6 versus 14.0, respectively) and higher mean EC (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), P (8.5 versus 3.9 mg/kg), and K (218 versus 193 mg/kg). 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 Sodium Adsorption Ratio change at the Miles City test plots was undetected with compost treated plots exhibiting both higher and lower SAR values compared to the control.

Vegetation Performance

Vegetation performance was greatly enhanced on all plots treated with compost as compared to the control plots that received no compost treatment. This includes both Happys Inn and Miles City research plots. It is too early in the study to determine differences in compost blankets and compost incorporation. To date, results indicate that the differences between the two compost amendment techniques 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 2005. This may be due to the drought conditions favoring annual plants. It is anticipated that the perennial grasses, once well established, will displace these annual plant species. Overall, the native plant establishment on all of these research plots was on a trajectory of becoming robust, self-perpetuating plant communities.

Erosion

Preliminary results have shown that the 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. However, compost addition alone often reduces soil loss from bare slopes. The compost blanket treatments in particular protected the mineral soil from detachment by providing a barrier against raindrop impact. Compost blankets also have significant water holding capacity and retard stormwater runoff simple by absorption of precipitation. 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.

Summary

Erosion from steep slopes is a prevalent problem at construction sites and along transportation corridors. Replacement of topsoil on steep slopes is commonly 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. Glacial till, marine shale and alluvial rock slopes have previously proven 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 two 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.

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