CASE STUDY: EFFECTIVENESS OF COMMERCIAL COMPOST SOIL AMENDMENT IN MONTANA UPLAND AND RIPARIAN REVEGETATION[1]

R. A. Prodgers[2]

Abstract. When using borrow dirt as cover-soil, revegetation often stagnates or declines in one decade or less, especially in cold, semiarid climates, due to infertility and lack of nutrient cycling. Fresh cover-soil is dirt; *soil* is distinguished by the organisms living in and on it. Compost amendment is intended to speed the conversion of dirt to soil by initiating an incipient soil food web. Compost provides microorganisms capable of degrading a wide variety of organic substances and the carbon and nutrients to sustain them until vascular plants provide fresh substrates and eventually a diverse array of food sources from root exudates to microbial cells. Or so it was thought when the two reclamation projects discussed in this paper began, one a Superfund remediation on Silver Bow Creek and the other waste dump reclamation at the Golden Sunlight Mine. The two projects are on opposite sides of the Continental Divide in southwest Montana. Applying and incorporating compost along Silver Bow Creek was easy; steep slopes at the gold mine limited both application and incorporation. One decade after seeding, microbiological analyses of composted and uncomposted soils failed to demonstrate greater diversity in composted cover-soils at the riparian Superfund site. Neither were short-term microbiological effects of compost amendment detectable at the hard-rock mine. Vascular plant cover likewise did not show a significant difference between composted and uncomposted treatments at the riparian site. This raises the question of whether introduced soil microbes drive revegetation or vice-versa, the vascular plants lead and soil microbiology follows. The microbiological activity that matters may be restricted mainly to the rhizosphere, at most a few percent of the bulk soil. Thermophilic microorganisms in moist compost simply may not survive in soils that dry and freeze. Soil biology may be one aspect of the recovery process that cannot be expedited using biologically active organic amendment. Compost specifications also are discussed.

Additional Key Words: nutrient cycling, soil microbiology, microbial diversity, compost specifications, reverse fertilization, rhizosphere.

---

[1] Paper presented at the 2013 National Meeting of the American Society of Mining and Reclamation, Laramie, WY ***Reclamation Across Industries, June 1-6***, 2013 and accepted for the online Journal of The American Society of Mining and Reclamation, Volume 2, No. 2, 2013. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Richard A. Prodgers is a Plant Ecologist, Bighorn Environmental Sciences, Dillon, MT 59725.
Journal American Society of Mining and Reclamation, 2013 Volume 2, Issue 2 pp 142-174
DOI: http://doi.org/10.21000/JASMR13020142

Introduction and Project Overviews

Some revegetation projects from road cuts to contaminated mine sites lack “topsoil” replete with organic matter (OM) and microorganisms, relying instead on deep borrow. One key to long-term revegetation success in such projects in a cold, semiarid climate is sustained nutrient availability from nutrient cycling. In two southwest Montana projects discussed here, one a riparian Superfund remediation and the other hard-rock reclamation, commercial compost is intended to initiate a soil food web as revegetation develops. This paper evaluates the effectiveness of compost to increase perennial plant cover and diversify decomposers.

The stream channel and floodplain of Silver Bow Creek for 20 miles below Butte, MT, the “Superfund” site, were contaminated with mine waste (mainly tailings) over one century ago (Fig. 1). Following contaminant removal, cover-soil originating as deep borrow was spread to bring the floodplain to grade. Thickness of the cover-soil varied but averaged from around 1.5 dm (6 in) to twice that. The borrow material was predominantly biologically inert. Compost applied as a cover-soil amendment has been an important element of the revegetation program with approximately $148 million spent as of 2010, excluding several hundred thousand dollars for application/incorporation. This project is called the Streamside Tailings Operable Unit, and the acronym SSTOU is used in this paper.

At the Golden Sunlight Mine (GSM), amending cover-soils (mainly on waste-rock dumps) with compost and a commercial mycorrhizal inoculum was negotiated with regulators in exchange for reduced cover-soil thickness over waste-rock dumps. The feedstocks for this compost consisted of more cow manure and less wood chips than the one used on SSTOU. The challenges of spreading and incorporating compost on slopes steeper than 3:1 is that when one uses a different compost it provides a contrast to the SSTOU.

Compost Explained

Composting is the exothermic transformation of biologically decomposable material through a controlled process of biooxidation that results in the release of CO_2, water, and minerals, and in the production of stabilized OM (compost) that is *biologically active*. It is a natural biological degradation process that is controlled and accelerated at a composting facility. The biological composting process follows a similar course regardless of the organic materials present in feedstocks. Important practices for commercial composting include:

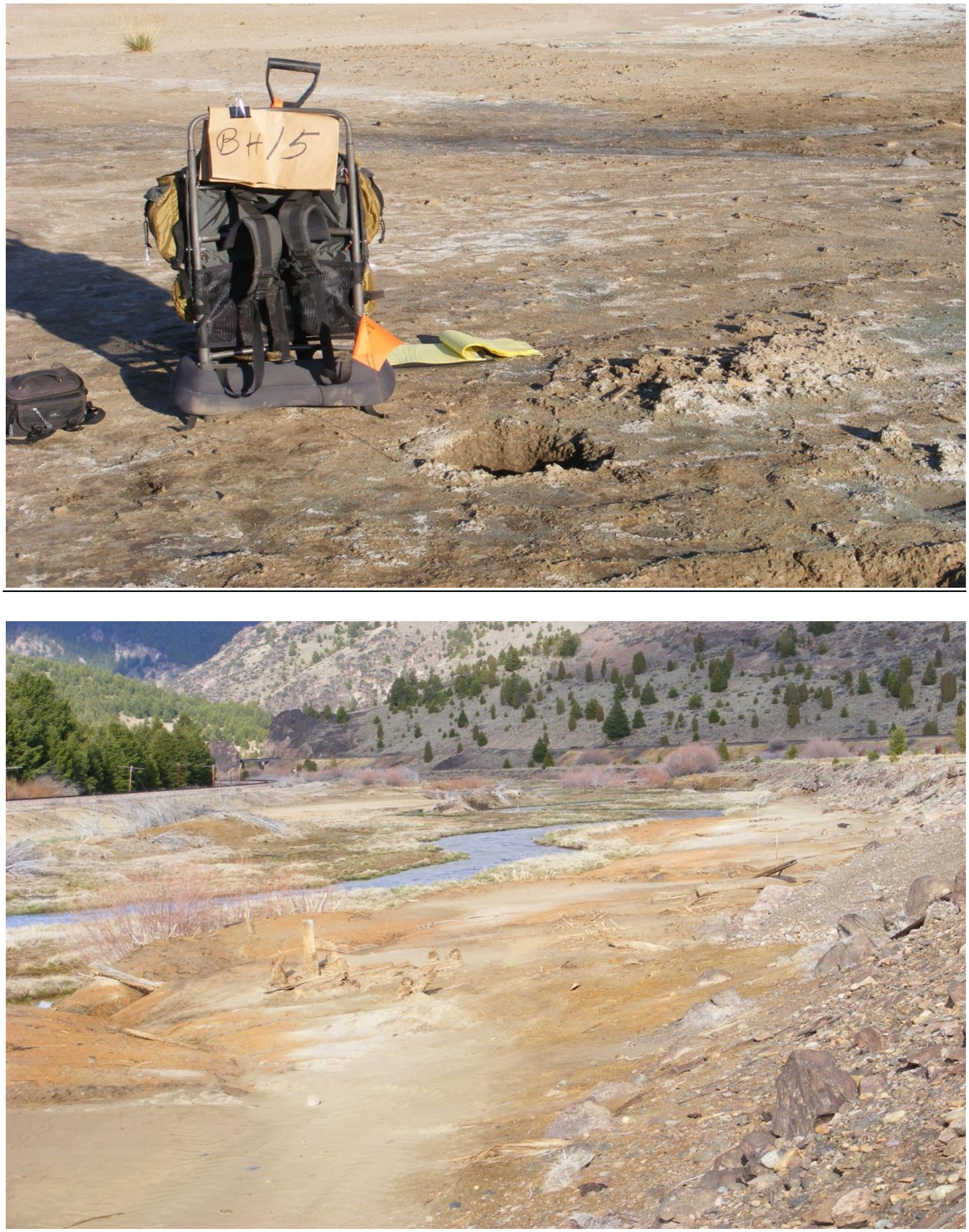

Figure 1. Pre-remediation Silver Bow Creek ranged from continuous deposits of mine tailings to a more complicated pattern of contamination and impairment.

<u>Aeration</u> To maintain optimum conditions for aerobic microbial activity; to buffer pH and immobilize NH_3; to remove heat, CO_2, and moisture; to strip volatile compounds; and to avoid odor generation and anaerobic conditions, which kills beneficial microorganisms.

<u>Temperature Control</u> Exothermic composting reduces pathogens, which is a fundamental requirement for feedstock processing, and destroys most weed seeds. Temperature control maximizes the rate of decomposition both during the high temperature thermophilic phase and afterward during the mesophilic phase.

<u>Addition of Make-up Water</u> To maintain moisture content for aerobic conditions, and to maximize organic decomposition. This may have ramifications for compost applied in semiarid climates.

<u>Mechanical Agitation</u> Turning to thoroughly mix make-up water and air uniformly throughout the decomposing mass, to break up air channels and clumps, to prevent fly reproduction, and to produce a uniform product.

<u>Compost Curing</u> Row increases biological stability, may further reduce pathogens, and with aeration eliminates organic phytotoxins. The degree of curing should match the intended use of the product. A bagged product will require a high degree of curing because of its potential use as potting soil and garden bed amendment. Products that will be sold in bulk for direct application for agricultural, landscape, roadside, or reclamation settings may not require as much curing as compost used as potting soil.

<u>Compost Screening and Refining</u> These are the final steps. If waste wood is a feedstock, the bigger pieces are relatively unreactive and enduring. Wood and bark become carbon sinks after a few years.

<u>Potential Benefits of Compost</u>

Compost proponents often wax eloquent about the wonders of compost. This quote came from a column on composting:

> "A teaspoon of normal mature compost or soil has hundreds of millions of bacteria, several miles of fungi, thousands of protozoa, a couple dozen nematodes, and some microarthropods present…"

Like diversity, perhaps the benefits may be overstated and overgeneralized but actually depend upon the specific product and the use to which it is put. The context for amending cover-soil with compost is that both SSTOU and GSM cover-soils originate mainly as deep, biologically inert borrow. In the riparian project, about six inches of weedy topsoil (the most biologically active portion) at the borrow area was graded off before excavation. Fresh cover-soil is dirt; *soil* is distinguished by the organisms living in and on it. Compost is intended to speed the conversion of dirt to soil. I see these possible compost benefits for revegetation:

- Establishes nutrient cycling otherwise lacking
- Helps build soil macrostructure
- Short-term fertilization
- Formation of humic substances/acids that chelate nutrients and toxic substances in the soil.
- Slight increase in water-holding capacity of coarse soils
- Slight increase in aeration in heavy soils
- May decrease crusting in soils that tend to form a surface crust
- May complex heavy metals (contaminants) on organic colloids
- Promotes plant establishment from seed in saline soils.
- Improves vascular plant health by otherwise mediating soils/roots.

<u>Nutrient cycling:</u> of these potential benefits, I rate nutrient cycling as more important than all others combined. Long-term revegetation success requires cycling in which nutrients are alternately immobilized in organisms and their residues are briefly available to vascular plants in mineral form in the soil solution. This quote from Alexander (1991) Chapter 9 sums up the decomposition role of microbes in the soil:

> "Organic matter originates as plant litter, subterranean portions of plants, animal tissues and excretory products. Thus "organic matter" refers to a heterogeneous collection of substrates, which soil inhabitants use to capture energy and carbon for cell synthesis. With molecules as different as cellulose, hemicelluloses, proteins, pectin, starch, aromatic hydrocarbons, etc., the initial steps of decomposition differ; the final steps involve only a few simple sugars and organic acids. *There is a certain underlying unity in metabolic reaction* (emphasis added). It is the attack of complex molecules that limits the rate of decomposition, and most intermediates probably are broken down as quickly as they are produced. For those microorganisms that utilize cellulose (for example), the long-chain carbohydrate is converted into simple sugars such as glucose. The conversion itself

provides no useful energy for the decomposing species, but it is a necessary precursor to the metabolism of the glucose."

Adding compost to cover-soil attempts to initiate a useful degree of nutrient cycling quickly, accomplishing in a few years which otherwise might take decades or longer. Eventually, the most recalcitrant substrates accumulate in the soil as humus. The important thing for enduring success is that revegetation not fail for lack of available mineral nutrients even as undecomposed organic substrates (replete with nutrients) accumulate in the soil.

The next benefit, soil structure, is part of soil genesis. Microaggregation in the 20-250 μm size class is governed mainly by encrustation by microbial residues around fragments of relatively recent (actively decomposing) plant debris. This requires continuous input of plant matter as does the next larger size of aggregates. Macroaggregates (>250 μm, visible structure) are stabilized aggregates of primary particles or microaggregates. Fine and very fine plant roots and mycorrhizal hyphae are important structural components in this aggregate size. As is the case for nutrient cycling, primary productivity and a functioning soil food web are required to maintain macrostructure.

<u>Fertilizer effect:</u> If an immediate effect of applying compost is evident in vascular plants, it results from fertilization. Mineral nutrients, not just macronutrients but also micronutrients if lacking, will boost growth. In early revegetation including Reach A of the SSTOU, I measured the available macronutrients in compost and adjusted the fertilizer rate downward in light of compost's contribution. However, it soon became evident that after a few years, residual compost became a carbon-rich nutrient sink, and since repeated fertilization is not desired (if only because of the damage to woody plants caused by spreading equipment); I decided to calculate fertilization rates ignoring the compost's contribution. However, if using a short-lived manure-based compost of high fertility, plant-available N, P, and K definitely should be considered in determining the need for mineral fertilizer. Even more than wood-based compost, manure compost presents establishing plants with great fertility during the vascular plant selection phase to be replaced by a much less fertile enduring condition. I prefer that the environment in the plant selection phase approximate the long-term condition insofar as possible.

Chelation This refers to a loose binding by organic molecules, often very complex, that can subsequently act as a slow release for nutrients and a more reluctant releaser of toxic substances, e.g., metabolites. Chelation can play a role in plant health.

Compost is claimed to increase water-holding capacity. The dirt has a certain water-holding capacity as does the compost, and obviously the outcome depends on characteristics of both. Compost increases volume of amended dirt, so there is always, in my experiments, an increase in short-term water retention after the mix is brought above field capacity and allowed to equilibrate. Probably most practitioners are more interested in water retained after a few weeks (or months!) without rain. At this point, compost-amended dirt may have an advantage over straight dirt, or it may go the other way. My own experiments, not reported here, have indicated up to a 2% advantage for straight dirt and up to a 5% advantage (by weight) for compost-amended dirt, this with about 5% dry compost by weight, which is more than typically used in revegetation. The differences are less than many suppose, and for some textures, the practical problem is getting water into the dirt rather than how much it retains. Changes to water-holding capacity are limited because applying enough compost to materially improve soil water-holding entails "reverse fertilization," explained later.

Aeration The aeration of heavy soils generally has not been an issue within the SSTOU except for one source used in two reaches, some of which was clay loam texture. The heavier soil textures at GSM would make additional aeration more desirable, but manure-based compost was less effective in this respect than a wood-based one. The effect, if any, would be virtually impossible to quantify.

Reducing crusting One reason that compost was used was to amend cover-soil at GSM, especially calcareous cover-soils. Compost effects would be difficult to quantify because tests such as modulus of rupture are inherently difficult.

Complexing Heavy Metals The "tying them up" hence unavailable to vascular plants, can occur where those metals could interfere with successful revegetation. However, those same metals inhibit biological activity in the organic amendment, which was the main reason for applying compost. In other words, the OM becomes largely inert if loaded with Cu, Zn, As, etc. In unremediated, metal-contaminated soils, OM can be a reservoir of contaminants.

The positive influence on plant establishment in saline soils is not entirely clear to me, but it may be another aspect of chelation, binding salt ions on organic molecules and perhaps lowering the soil osmotic potential. Technically, chelation refers to an organic chemical with two or more functional groups that can bind with metals to form a ring structure, so I am using the term loosely. In the field, compost does appear to promote seedling establishment in saline soils.

Other aspects of plant health that may be affected by compost are frankly over my head – but that doesn't mean that they are unimportant.

Summing up, good compost is a reservoir of carbon and nutrients supporting indigenous populations of a diverse array of microorganisms that, one hopes can degrade a different set of fresh substrates found in revegetated soils. Ancillary benefits alone do not justify the cost of compost, which has tripled since the SSTOU started using it in 2001.

For wood-based compost, the flip side of initial mineral nutrients is reverse fertilization, especially if too much compost is applied. The negative effect on vascular plants has been documented in several SSTOU monitoring reports. Of course, the C:N ratio of the product as purchased is one of many properties relevant to deciding whether a commercial compost product is acceptable. However, recalcitrant compost food-stocks are critical to what happens within a few years after application. The compost used for the SSTOU project was typically a mix of sewage sludge or manure, grass clippings, possibly with herbicides, and wood waste from sawmills, but wood visibly dominated the finished product (Fig. 2). The product used at GSM had more manure and was more fertile initially and less enduring in its physical effects.

In evaluating compost, the C:N ratio is rarely overlooked. About 20:1 or less is considered acceptable, but the actual point of equilibration between mineralization and immobilization can be 5:1 to 20:1. As Killham says in Chapter 4, "Rarely can the C:N ratio alone indicate whether mineralization or immobilization will occur, or the decomposition rate." The labile constituents are pretty well used up in the composting process. Following application, mineral nutrients are soon immobilized in growing plants and dead microorganisms. That is why an immediate boost to vascular plant growth is usually evident when compost is applied. The high-C components (e.g., wood or straw) endure, remaining visible for years in or upon the soil. Now it goes the other way. It is complicated, and our soils are often dry and inactive, but right when the vascular plants want to put on a burst of growth in May-June, the wet months, the wood, (lignin, cellulose, hemicellulose) acts as an N sink. That's reverse fertilization. Applying more compost typically provides more plant-available nutrients in the establishment phase followed by a very

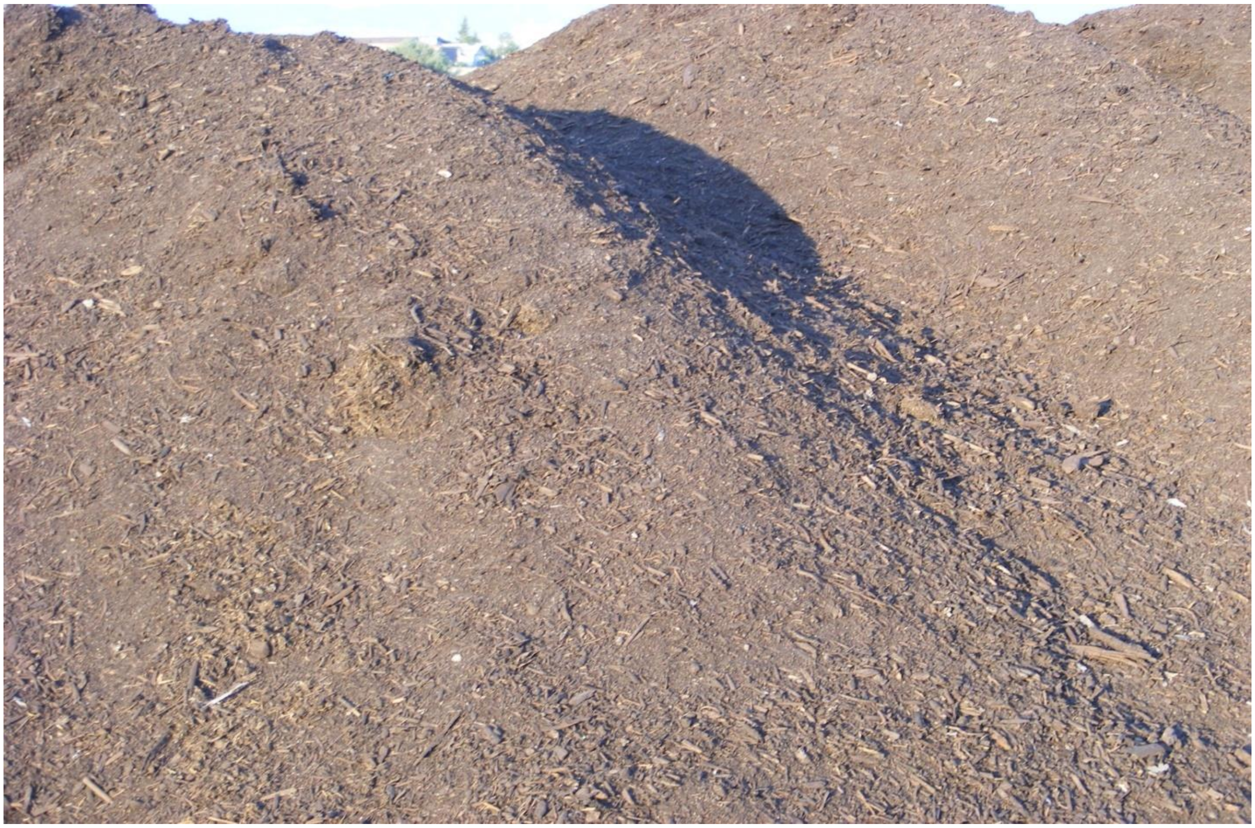

Figure 2. The three main feedstocks for commercial compost used on the SSTOU are wood chips, sewage sludge, and yard waste, but wood visually dominates the finished product. Pieces smaller than 9.5 mm (3/8 in) does not enter the C:N ratio calculation because it is screened before analysis.

infertile condition in a few years and a decline in vascular plant vigor and abundance. The effect has been quite pronounced (Fig. 3).

Looking at Fig. 2, it is hard to believe that the C:N ratio is 20:1 or less as reported. It turns out that before analyzing in the laboratory, compost is screened to -9.5 mm or 3/8". The C:N ratio should be called the *available C:N ratio.* The primary constituents of wood are cellulose, hemicelluloses, and lignin. All are long-chain carbohydrates lacking plant nutrients. The outstanding feature of lignin is it resistance to enzymatic degradation. Decomposition is slow compared to cellulose, hemicellulose, and other carbohydrates. The lignin in most organic materials protects associated carbonaceous substances from destruction, probably by virtue of a physical or physiochemical barrier set up by the close inter-linkage between lignins and cellulose/hemicellulose in the plant cell wall. In other words, lignins may separate or protect more easily assimilated compounds from microbes/enzymes.

What about the wood that doesn't go into the C:N calculation? One can imagine that N from polypeptides or amino acids could provide the N, and then wood degradation could occur even though the wood acts as an N sink. But it's not a smorgasbord. Degradation can be bottlenecked by lack of exoenzymes capable of breaking down the initial huge polymers alternatively, by lack of water or limited surface area. So wood can persist but still at times make N from degradation of other substrates unavailable to vascular plants.

For the SSTOU project, I selected the initial compost application rate based on my understanding of the desired benefits with emphasis on nutrient cycling. It was applied in different areas at about one percent in the upper 1.5 dm (6 in) of cover-soil or 1.5% in the upper decimeter (4 in). A compost vendor persuaded management to experiment with double the prescribed rate at two locations. This failed to provide a noticeable short-term benefit, but in a few years the negative consequences (plant mortality and diminished plant cover) were all too clear, particularly in Reach C, where a very wood-rich compost was applied (upper Fig. 3). Impaired revegetation also was evident near temporary compost storage piles where wind deposited additional compost (lower Fig. 3). This required subsequent mineral fertilization, which is exactly what using compost was supposed to preclude. By then, some native species (e.g., big sagebrush) diminished or disappeared. In general, microorganisms require the same inorganic ions as higher plants, and where the nutrient supply is limiting, the microorganisms get them (Alexander 1991, p. 384).

Compost Specifications

Speccing compost is difficult, which has led some purchasers to forgo specifications, even pricing it volumetrically (m^3 or yd^3) no matter how much dry organic matter is present per unit volume. But some properties of compost can be deleterious, and different laboratories can arrive at very different quantifications of compost properties. Standardizing protocols by using a laboratory approved by the Composting Council is good practice. Compost is not soil, and methods appropriate to analyze soil may not work for compost. Non-approved laboratories may provide good analysis, but as is next demonstrated, they may not.

Figure 3. Reverse fertilization is evident where twice the usual compost application rate was applied (upper photo) and where a compost stockpile had been located (lower photo).

In the early days of SSTOU revegetation, I undertook a comparison of two commercial compost products. By serendipity, the same two products were used in the reaches investigated for this report. Compost B was from the vendor who provided compost for Reach A, whereas Compost A was from the supplier (now differently owned) that provided compost for Reaches J and K. In evaluating a compost product or effect on revegetation, it is unavoidable that the properties of different batches will vary. Feedstocks may change, or some aspect of the process may stray beyond desired parameters, such as "going anaerobic." Even weather can have an effect, especially at the extremes. Delivered compost is stored in oxygen-depleted piles that freeze near the surface, so there are temporal variables.

Common parameters were analyzed by five different laboratories for both composts. The upshot is that analytical data must be viewed with a surprisingly large degree of uncertainty. For example, the SSTOU project purchased organic matter in a compost matrix based on price per unit mass of organic matter, assuming specifications were met. Data provided by the Compost B manufacturer (for the bid) indicated around 90% OM content, which was suspiciously high but resulted in that product winning the bid. Later, the mean OM content from five laboratories was 74% with a 90% confidence interval of ±24%, so we can be fairly sure it was not less than 50% nor higher than 98%. One laboratory did report 98%, but that was probably incorrect, so the calculated application rate for Reach A may not have put as much OM into the soil as desired. (Actually, organic C is measured in laboratories and an empirical constant is used to compute "organic matter," which is usually desired by clients, so the choice of multiplier may account for part of the differences as well as the actual measurement of organic C.)

The range for each parameter is reported next for the two compost products. Samples submitted to each laboratory were split from a common composite sample.

<u>Organic Matter, Moisture, and Fertility</u>

Organic Matter (loss on ignition):
Compost A: 26 to 43%
Compost B: 50 to 98%

Percent Moisture:
Compost A: 36 to 44%
Compost B: 55 to 62%

Mineral N:
Compost A: 1,000 to 1,800 ppm NO_3 and 0 to 2,900 ppm NH_4
Compost B: 260 to 780 ppm NO_3 and 480 to 4,160 ppm NH_4

Plant-Available Potassium (by ammonium acetate):
Compost A: 2,680 to 3,560 ppm
Compost B: 2,400 to 3,460 ppm

Plant-Available Phosphorus (by sodium bicarbonate or Olsen method):
Compost A: 250 to 750 ppm
Compost B: 1,550 to 2,710 ppm

Summing up, the number of significant digits quantifying compost properties commonly overstates the actual accuracy of results, and the confidence intervals for data from multiple laboratories can be substantial. Compost B is superior to A in most respects, but the prevalence of ammonium over nitrate can be construed as a symptom of immaturity.

In speccing compost, moisture content, bulk density (from weight scales), and organic matter content are used to derive the cost per dry unit mass of organic matter and the application rate to achieve the desired amount of compost per unit area. These data are critical. The other specifications are to assure a good product.

My eyes go first to the “cucumber test” wherein straight compost is used as potting soil. First, seed germination is reported. This may not be precisely quantified (as in a seed germination test) as 100% is often reported. The second number is percent wilt. I have seen data reporting 100% germination and 100% wilting (plant death). While compost will be greatly diluted in cover-soil, this is a red flag. If salinity is OK, herbicides from lawn clippings are one suspect usually not tested for specifically.

On SSTOU, we require these analyses; laboratories provide guidance to interpreting the numbers:

<u>Required Soil Testing Assurance Compost Council Analysis</u>

<u>Sieve Size, Volume Distribution and Inerts, and Bulk Density</u>
Method TMECC 02.02-B - Sample Sieving for Aggregate Size Classification.
Method TMECC 02.02-C - Man Made Inert Removal and Classification.
Method TMECC 03.03 – Bulk Density- If due to the volume required for analysis of Wet Bulk Density by TMECC Methods, DEQ is requiring Wet Bulk Density from other lab methods.

<u>Stability</u>

Method TMECC 05.08-B - Carbon Dioxide Evolution Rate
Method TMECC 05.08-F - Biological Available Carbon

<u>Maturity</u>

Method TMECC 05.05-A - Germination and Growth

<u>Nutrients - Primary and Secondary</u>

Method TMECC 4.02-D - Total N
Method TMECC 4.02-C – NH_3
Method TMECC 4.02-B - NO_3
Calculate Organic Nitrogen
Method TMECC 4.03-A - Phosphorus
Calculate P as P_2O_5
Method TMECC 4.04-A - P
Calculate K as K_2O
Method TMECC 04.05 – Ca
Method TMECC 04.05 – Mg
Method TMECC 04.12-D/IC - Sulfate

<u>Nutrients - Trace Elements</u>

Method TMECC 04.05-Cu
Method TMECC 04.05-Zn
Method TMECC 04.05-Fe
Method TMECC 04.05-Mn

<u>Salts, pH, & Carbonates</u>

Method TMECC 04.05-Na
Method TMECC 04.05IC - Cl
Method TMECC 04.11-A - pH
Method TMECC 04.08-A - Carbonates as $CaCO_3$
Method TMECC 05.07-A - Organic Matter
Method TMECC 04.01 - Organic Carbon
Method TMECC 03.02 - Ash
Calculate C/N Ratio
Method TMECC 03.09 - Moisture
Method TMECC 04.10-A - Electrical Conductivity.

<u>Metals</u>

For the following heavy metals: As, Cd, Cu, Pb, Mo, Zn
Method (listed metals) EPA 3050B / EPA 6010
Method (listed metals) TMECC 04.12-B / 04.14-A
Method (Mercury) TMECC 04.06 / EPA 7471

Bacteria

Standard Methods 9221E – Fecal Coliform

SSTOU used the price per dry metric ton of organic material supplied in evaluating the bid price. Salinity must be less than 20 dS/m because some soils to be amended are saline. In addition, failure by compost to meet any of the parameters listed above, such as metals, stability, and maturity, will cause rejection of the bid.

However desirable, we have found it impractical to require microbiological analyses because there is no undisputed standard or "best" method, and different microbiological laboratories (of which there are few in the west) analyze somewhat different properties. Bids could be disputed if a product was rejected based upon "subjective" analysis. In one case, however, root-feeding nematodes were reported, something the buyer might wish to consider in evaluating the cost-effectiveness of compost amendment.

Revegetation Practices and Conditions

Streamside Tailings Cover-soil and Reclamation Practices

Composted and uncomposted revegetation was available for comparison in two portions of the SSTOU. About three-quarters of Reach A was composted and seeded in spring 2001 and was nine years old when soil microbiology was sampled in 2010. The other one-quarter of Reach A was uncomposted but otherwise treated identically. Representative composted and uncomposted revegetation is shown in Fig. 4.

About 16 km (10 mi) downstream, a portion of Reach K was composted with a different product (Compost A in the earlier analysis) and seeded in spring 2009, but the old stream channel there comprised in situ soil and was uncomposted. I sampled this area just one year following seeding.

In the SSTOU then, I initially evaluated two compost products and two field ages. In August 2010, a single ad hoc cover-soil sample from composted and uncomposted portions of Reach J was collected for analysis. A steep-banked channel that precluded compost-spreading equipment provided the control. Both received typical cover-soil from the Erickson Pit. Both were seeded with Sub-irrigated Seed Mix in fall 2008 and sampled in the second growing season.

Figure 4. Six-year-old sub-irrigated revegetation, SSTOU, in composted (upper photo) and uncomposted areas (lower photo).

<u>Cover-soil</u>

In Reach A, cover-soil originated at Borrow Area #10, which consisted of decomposed granite of light sandy loam texture grading toward loamy sand. Some consider a good sandy loam to be nearly ideal for revegetation. Loamy sand texture has too little water- and nutrient-holding capacity and was not supposed to be used for cover-soil, but it probably was included in places.

Change Order 25 in Reach K was not cover-soiled in the usual sense of applying dirt from a borrow pit. Instead, a sideslope of unconsolidated or slightly consolidated material, probably tertiary valley-fill, was cut back using dozers and spread across the floodplain to provide cover-soil throughout a 10 ha (25 ac) area. The slope was cut back 9 m (30 ft) or more. The minimum thickness of fill was 2 dm (8 in). Texture was variable but typically sandy loam. The cover-soil here was not tested before seeding, but one expects it was biologically inert until composted.

Two and one-half of 10 ha (6 of the 25 ac) was an old channel that was partially excavated to remove contaminants. Most of the west end was cover-soiled, but less of the eastern portion due to the channel filling with groundwater and/or runoff. While contaminated, most of the channel supported plants to some degree before remediation, so one would expect remnants of a functioning but impaired (due to contamination) soil food web. Reach J received Erickson borrow, the properties of which vary throughout the pit, but most often sandy loam with less than 35% rock fragments.

Compost Application

Commercial compost was procured by bid based on cost per unit mass of dry OM. In other words, the project purchased OM in a compost matrix. The application rate is expressed as weight OM/ha/depth of disking (about 1.5 dm) with an assumed cover-soil bulk density of 1.5 g/cc. Figure 5 shows a typical application rate. The application rate can be converted to m^3 or yd^3 of compost/ha or acre using data provided by the vendor based upon laboratory analyses and truck-scale weights. As explained, a diverse assemblage of soil microorganisms that abets nutrient cycling is desired. OM in compost sustains them until revegetation establishes and provides fresh food sources. That's the theory.

We specify numerous compost tests to assure a good product and further specify that the analyzing laboratories conform to Composting Council methods and protocols. Despite the earlier quotation about the underlying unity of metabolic reaction, it could be viewed as a leap of faith to assume that the microbial populations in a given compost product are the ones required for nutrient cycling in revegetation, or that thermophilic microorganisms will survive in a cold, semiarid environment until new food sources become available.

Figure 5. Compost as applied to cover-soil with a Terragator; compost and fertilizer were disked simultaneously to about six to 15 cm (4- to 6-in) depth.

In Reach A, the general contractor applied compost in spring 2002 to the floodplain and a few selected uplands. The quantity of Glacier Gold compost applied was calculated to add 1.0% OM to the upper 1.5 dm (6 in) of cover-soil. Glacier Gold compost had an extremely high OM content (91% OM claimed), which is almost double the amount typically encountered in compost. (This was before we required Compost Council protocols. The amount of OM applied was probably less as revealed in the compost characterization data from different laboratories presented earlier.) The amount of bulk compost applied was just 63 m^3/ha (32.5 yd^3/acre). Compost in Reach A was applied with a TerraGator® and disked in with mineral fertilizer (applied separately) using typical farming equipment. The fertilizer rate was based on cover-soil fertility and the "plant-available" mineral macronutrients in the compost.

Change Order 25 comprised 10 ha (25 ac) requiring treatment. This floodplain area was remediated in 2008-09 and first seeded in spring 2009. Big Butte aka BioLogic compost was applied by a TerraGator® at 1.5% OM in the upper decimeter (4 in), to which depth it was disked without additional fertilizer at that time. The amount of applied OM (not compost) was theoretically very similar in Reach A and CO 25, but different products were used.

In CO 25, the uncomposted remnants of an old stream channel differed in several respects from the adjacent cover-soiled, composted floodplain. It was too wet to cover the soil uniformly or apply compost, and furthermore it was not seeded the same way as the prevalent floodplain area. It was hand-broadcast seeded with a different seed mix. Comparison of plant cover would reflect major differences in substrate and revegetation materials and practice in addition to compost. Thus, microbiological analysis is the only basis to evaluate compost effectiveness in CO 25. The same amount of compost was applied in Reach J.

By luck, I have microbiological analyses of the two compost products, Glacier Gold and BioLogic, dating to the early 2000s. This is reported in the Results section. Of course, properties vary from batch to batch and year to year.

<u>Seeding</u>

Reach A was seeded in spring 2001. The hydrologic zones recognized in all subsequent revegetation were then identified: wetland, transition zone, sub-irrigated, and upland. Each hydrologic zone (or soil moisture regime if you prefer) has a corresponding seed mix. Typically, heavy (<300,000 seeds/lb) and light seed are purchased in two sets of bags and applied sequentially, the heavy seed drilled and the light seed broadcast, sometimes followed by a roller or chain harrow. Areas that didn't start promisingly were hand-seeded that fall, and subsequent disturbances such as the overflow channel removal were seeded later but not sampled for microbiology.

Change Order 25 was seeded in spring 2009 following compost application, but fertilization was delayed. It was seeded in two passes with the sub-irrigated seed mix, a fine mix for species diversity while providing good plant abundance. Those areas too wet to compost or mechanically seed (including the presence of standing water) comprised the control or uncomposted areas. I hand seeded the uncomposted areas in late spring. The ponds continued to drop and essentially dry up. I again hand seeded in July as fresh substrate was exposed. Then in fall 2009, Western Reclamation seeded a mix called "Moist and Salty" in the un-vegetated areas along channels and even some of the dry bottoms. The rest of the floodplain, the composted part, was fertilized in fall 2009. A slope on the Craddock property was seeded with a grazing mix and compost subsequently scattered on the surface (the slope limited application and precluded incorporation); one sample was taken there.

Golden Sunlight Mine Reclamation Practices

While there are benches and tailings ponds, slopes of 3:1 to 2:1 are prevalent at GSM's waste-rock dumps (Fig. 6). The two main revegetation goals are to prevent cover-soil erosion and transpire soil water, so it does not percolate down to un-oxidized acid-generating waste rock. The agencies Montana Department of Environmental Quality (MDEQ) and federal Bureau of Land Management (BLM)) originally stipulated 6 dm (2 ft) of cover-soil over 6 dm of pH-neutral oxide; the oxide layer was to prevent acid vapors from underlying waste rock contacting the cover-soil.

GSM and the agencies negotiated alternative cover-soil requirements including rock content, calcium carbonate equivalence, bringing the upper decimeter (4 in) to 1% OM, and a mycorrhizal amendment. In exchange, the oxide requirement was dropped (oxide that did not generate acid when water was added turned out to be more scarce than originally estimated) and total cover-soil thickness was reduced by varying degrees depending upon slope (flat, 3:1, or 2:1).

For slopes of 3:1 or less, cover-soil was brought to depth and grade, compost was applied (e.g., with a manure-spreader) and disked in much as it is in the SSTOU. However, the application rate was less than on the nearly flat slopes of the SSTOU and disking was more difficult. On slopes steeper than 3:1, and GSM has many 2:1 waste-rock dumps, compost was mixed with cover-soil at the dumpsite (usually a bench or wide road) and then pushed down the slope to grade. In practice, compost distribution in the cover-soil matrix was inconsistent, and lack of oxygen limits biological activity more than a decimeter or two.

Figure 6. 2008 waste-rock-dump revegetation at the Golden Sunlight Mine.

Methods

Cover-soil Sampling for Microbiological Analyses

Microbial activity is severely curtailed in dry soil, so most sampling in the SSTOU occurred in mid-May 2010. Soils at that time still contained recharge from melted snow and precipitation. Precipitation in May 2010 at the Butte Airport was almost 7 cm (2.7 in) compared to the 35-year mean of 5 cm (1.9 in.) A change in temperature will alter the species composition of the active flora, so a somewhat different result might have been observed in June. Microbial activity frequently is greatest at 60-80% of water-holding capacity. Vascular plants were actively growing at the time of sampling, although residual plant litter dominated the visual aspect.

In Reach A, the oldest revegetation, four samples were taken in composted and uncomposted locations paired to the extent possible for a field study. For example, each treatment had one sample of upland rubber rabbitbrush, basin wildrye, and sheep fescue. The other three were in moister non-wetland soils dominated by basin wildrye and slender wheatgrass. One additional sample was taken from a saline soil in the uncomposted area, but it did not have a mate in the composted area. The invasive Garrison creeping foxtail, which was planted with EPA approval upstream, was avoided to the extent possible when locating samples.

Cover-soil was sampled at 6 to 10 spots per sample location using a 2.5 cm (1 in) corer. Occasionally, the corer plugged repeatedly without getting 1.5 dm (6 in) of soil, in which case a shovel was used. If sampled with a shovel, a shallow hole was excavated, then a slice taken from the side of the hole. This was winnowed to a narrow strip representing 1.5 dm of depth. A composite sample at each location was placed in a labeled, plastic bag, sealed, and put into a cooler with gel ice even though ambient temperatures were in the 50's during the warmest part of the day. Samples were shipped in the same coolers with ice for overnight delivery to BBC Labs in Tempe, Arizona.

At GSM, soils were sampled at five locations in August when soils were dry (undesirable, but sampling was done in conjunction with revegetation sampling). A more abbreviated sampling protocol was followed to save time. Cover-soil originating as deep borrow was sampled at three spots per sample location using a shovel by excavating a shallow hole, then cutting a slice from the side of the hole to represent the 1.5-dm-depth interval. Dirt from the three samples was combined into a single composite sample per location, which was placed in a labeled, plastic bag, sealed, and put into a cooler with gel ice. Samples were shipped that day in the same coolers with ice for overnight delivery. BBC Labs performed the microbiological analysis, same as for SSTOU.

<u>Vascular Plant Monitoring</u>

Revegetation in each Reach of the SSTOU was monitored in rotation during the performance-evaluation period using the same transects and methods. Reach A with 17 transects was last sampled in 2007, when it passed the performance standards (further sampling not required). In Reach J, sub-irrigated zone, one transect each was compared in otherwise similar composted and uncomposted areas. In Reach K (CO25), revegetation could not be compared due to differences in seeding already explained.

Revegetation sampling combined canopy coverage (Daubenmire, 1959) from plots along transects and shrub density from one-meter-wide belts along the same transects. Revegetation was sampled along 100-meter transects. Canopy coverage was estimated in 20, 0.5 m^2 plots at 5-m intervals along each transect. Plant cover was estimated as accurately as possible; cover classes were not used. Shrubs density measurements are irrelevant to the comparisons here.

The long length of these transects reflects average site and vegetation conditions within a significant portion of a hydrologic zone better than shorter transects that have a greater chance of emphasizing aberrant spots. An attempt was made to place transects within a single hydrologic zone as mapped, but it turned out that hydrology in some cases changed since the early days when seeding and transplanting were implemented, so some transects traverse more than one hydrologic zones.

To avoid littering the floodplain and banks with permanent markers, transects are located by GPS coordinates only. Thus, identical plot locations are not assured, just the same approximate areas.

Data Analysis

Two approaches were used to evaluate the effectiveness of compost as a soil amendment:

1. Microbiological evaluation is further explained in this section.
2. Comparing perennial canopy-coverage data described above.

Microbiological Analysis of Cover-soils

Microbiological analyses were performed by BBC Labs in Tempe, Arizona, which ceased operation January 2011. (I engaged the same lab 10 years previous to evaluate compost microbiology.)

To have a systematic and manageable approach to soil microbiology, BBC Labs evaluates "functional groups," or sets of microorganisms often correlating to fundamental taxonomic divisions with common activity or association. Actual quantities of each group vary with the form and quantity of available nutrients and carbon, temperature, moisture, pH, predators, and other environmental factors. Thus, the ratios can be more indicative of function than absolute quantities. Functional group descriptions follow (from BBC literature with some annotations):

Heterotrophic Bacteria Aerobic bacterial most prevalent near the surface (oxygenated zone) in neutral to alkaline soils. They can suppress plant diseases in addition to playing an important role in decomposition. This type of bacteria also is prevalent in compost and is quantified by BBC Labs as Colony Forming Units (CFUs).

Fungi (yeasts and molds) These include decomposers as well as mycorrhizal fungi. Fungi are most prevalent and major agents of decay in acidic soils. They are important for breaking down organic compounds, nutrient cycling, and controlling plant diseases. Their distribution in the soil is tied to the location of oxidizable carbonaceous substrates. Their strong dependence on O_2 probably explains their concentration in the decimeter or two of soil. Likewise, they usually are absent from swamps, bogs, and un-drained peat. Quantity is typically several orders of magnitude less than bacteria in grassland soils.

Nitrogen-Fixing Bacteria The free-living ones, not the ones that form root nodules on legumes. Many genera are capable of nitrogen fixation. They are important in cryptobiotic crusts as are found in deserts, but I was unsure how significant they were to nutrient cycling in revegetation. However, Bob Linderman (personal communication) cautioned me not to be so dismissive; as usual, soil microbiology is more complicated than one might think. Bob's comment follows.

> "They have been used in inoculations, sometimes in combination with AM, and growth responses have been very positive. Some of these bacteria have much more growth-enhancing potential than just fixing atmospheric nitrogen; they produce rooting hormones and other growth factors too."

Actinomycetes These are bacteria that prefer aerated, alkaline soils. Actinomycetes are microorganisms that produce slender, branched filaments that develop into *hyphae*, collectively called *mycelium*. While often less important biochemically than bacteria or fungi, they are important on resistant components of plant/animal tissue. Thermophilic actinomycetes may be dominant in compost, evidenced by a gray color near the surface. They too can play a role in nitrogen fixation. Abundance is roughly in the range of fungi in the soil. They can be prevalent in compost with a lot of wood, such as the one applied to Reach A.

Anaerobic Bacteria These are obligate anaerobes and are basically used as an indicator that the soil is sometimes waterlogged or improperly drained; the role of facultative anaerobes is more nuanced.

Pseudomonads These are common and potentially fast-growing bacterial genus and are active in decay and nutrient cycling, P availability, plant growth, and in controlling plant pathogens. (It can also cause plant and human diseases.) The *Pseudomonas* genus once was huge; starting in the 1990s it was split into five other genera. Some can even denitrify.

BBC Labs evaluated what it called the species richness diversity of each functional group – the number of different types ("taxa" probably would be more appropriate than "species") in each functional group. "The index is derived from a standard microbial ecology formula that weighs the variety of species within a functional group from a normalized analysis of species richness against the total number of microorganisms associated with that functional group." The premise is that a wide variety of microorganisms can decompose many substrates. Diversity also "allows for a more varied and flexible response to varied environmental fluctuations and stress." Since BBC Labs ceased business in January 2011, there is no longer a website with further information.

Typically, the index would be highest for heterotrophic bacteria and fungi and lowest for free nitrogen-fixers. These are summed to provide an overall diversity index. Put into just three classes, the interpretation for soils (from BBC Labs) is:

	Summed Indices	
	Soil	Compost
High Diversity	>12.5	>6.5
Moderate Diversity	7-12.5	3-6.5
Low Diversity	<7	<3

Of interest to this investigation is both the diversity rating *per se* and whether indices for composted and uncomposted cover-soils differ.

Results

Compost effectiveness in revegetation here is evaluated in two ways. The success of revegetation itself is the ultimate goal; it can be measured directly and judged after a decade or so, although an even longer time frame is desirable. Since all revegetation was, when sampled, less than one decade old, trend is important in inferring permanence. The limitation is that only a few (previously enumerated) places in the SSTOU have an uncomposted control area for comparison, and at GSM, compost amendment is a recent development, so only two-year-old cover-soils were sampled. The second approach is direct microbiological evaluation. The limitation is that while microbiological attributes can be measured, the critical nutrient-cycling role is not directly measured but rather inferred.

Characterizing Commercial Composts Used on Silver Bow Creek

Microbiology

Two laboratories evaluated different parameters. The second, BBC Labs, was also used in 2010, so the first analysis is quickly summarized without discussion of each parameter.

Bacterial Biomass

Compost A	Excellent
Compost B	Excellent

Fungal Biomass

Compost A	Too Low
Compost B	OK

Fungi Hyphal Diameter Both have “great sets of species of fungi.”

Ratio Fungi: Bacteria

Compost A	Far Too Low
Compost B	Too Low

Protozoa (density, #/g)

	Flagellates	Amoebae	Ciliates
Compost A	9,500	9,500	<100
Compost B	70,700	5,500	2,100

Both OK but B is better. Expect flagellates>amoebae>ciliates.

Nematodes (#/g)

Compost A	Low, Poor Diversity
Compost B	Low, Poor Diversity
	No Root-Feeders in Either

The approach used by BBC labs was explained in the data analysis section. The most important finding expressed here is that both compost products were acceptable, but at the same time both had moderate microbial diversity, which is taken to connote effectiveness in nutrient cycling.

Compost Stability (mg O_2/kg Compost)

Compost A	20	Good for field, OK for horticulture
Compost B	6	Good for field or horticulture

Germination Rate, 1/3 strength (%)

Compost A	96	Good, >85% desired.
Compost B	103	Good, >85% desired.

Maturity Index (Phytotoxicity), 1/3 strength (%)

Compost A	91	Good, >85% desired
Compost B	95	Good, >85% desired

Salinity (Electrical Conductivity, dS/cm)		
Compost A	5.5	OK, a little high
Compost B	1.8	OK
pH (s.u.)		
Compost A	8.7	A little high, 6.5-8.5 desired
Compost B	5.1	Low, 6.5-8.5 desired.
Heterotrophic Plate Count -- Aerobic		
Compost A	Good	
Compost B	Good	
Anaerobic Bacteria		
Compost A	High	
Compost B	OK	
Yeasts and Molds		
Compost A	High -- good	
Compost B	High -- good	
Actinomycetes		
Compost A	OK	
Compost B	OK	
Pseudomonads		
Compost A	OK, high	
Compost B	OK, low	
Nitrogen-Fixing Bacteria (non-symbionts, not the ones that associate with legume roots)		
Compost A	OK, a little high = lower on free N	
Compost B	OK, more free N than A	
"Species Richness Diversity" (really taxon diversity)		
Compost A	5.2, medium.	
Compost B	6.1, medium, slightly better than Compost A	

Frankly, I am surprised that Compost B at pH 5 could rate so well, but as noted earlier, there may be some uncertainty associated with that number. Perhaps the most important thing to remember is that neither compost had high taxon diversity, nor on a different scale, diversity is being used to infer nutrient cycling in vegetated cover-soils.

Revegetation Performance and Trend -- SSTOU

Reach A is the oldest SSTOU revegetation. It was seeded in spring 2001. In 2007, revegetation in Reach A directly met the performance standards in Table 1 (Prodgers, 2008). (Directly means without statistical confidence interval.)

Table 1. Minimum Stratified Canopy Coverage Approximately 10 Years after Seeding in Years of Near-normal Seasonal Precipitation.

HYDROLOGIC ZONE	MEAN PERENNIAL CANOPY COVERAGE*	TRANSECTS MEETING COVER STANDARD
Uplands, Sub-irrigated	60%	65%
Stream banks, Transition Zone	80%	80%
Wetlands (not open water)	95%	65%

* Noxious weeds and nonnative annuals are not counted toward canopy coverage.

Did compost confer advantage to vascular plant performance? The range of perennial cover from 18% (still contaminated) to 106%, virtually assured no significant difference. The simplest comparison is that <u>the five uncomposted transects averaged 64% perennial cover, whereas composted areas (12 transects) averaged 70%.</u> While there are legitimate reasons to say that one transect or another should not be counted, this slippery slope manipulates the result, so we leave it at that. (This is not a perfect comparison as test plots might be.) For statistical significance, a far larger difference in mean plant cover or mean perennial plant cover would be required (or more samples) due to the many uncontrolled variables present in a riparian environment. One treatment will always have greater or lesser cover, and compost did not provide clear advantage. Most of the revegetation in both composted and uncomposted cover-soil "passed" the standards in Table 1, while poor spots were related to obvious edaphic limitations, mainly residual contamination or salinity. One also can conclude that satisfactory revegetation without compost was achieved in Reach A.

The trend in the data was the perennial plant cover from the prior sampling was upward. From 2004-2007, perennial cover in upland-sub-irrigated sites increased from 69% to 71%, whereas in the transition zone (moister), it increased from 93% to 99%. Again, these differences are far too small to be considered statistical significance. However, a crash due to infertility clearly did not occur.

In Reach J, both composted and uncomposted areas had grasses and legumes, and each, by freak coincidence, had 108% perennial plant cover in 2011. They were seeded in fall 2008.

Summing up the revegetation comparison, both composted and uncomposted cover-soils can support satisfactory revegetation within the time frame provided so far. The difference in total and perennial plant cover, while slightly favoring composted soils, is insufficient to ascribe statistical significance. The trend in plant cover in those reaches sampled along the same transects in at least two years was upward. It is unlikely, if not impossible, that the initial fertilization played a role beyond the second or at most third growing season. Nitrogen-fixation from inoculated legumes no doubt contributed to productivity and plant cover. However, the trend in Reach A plant cover was upward at the same time that legumes declined sharply.

Microbiology Results -- SSTOU

Results are quickly stated. Mean diversity for the composted samples in Reach A was 5.3 compared to 5.0 for the uncomposted samples. If a saline-soil sample was dropped from the uncomposted data, leaving equal sample sizes for both treatments, the difference was miniscule: 5.3 vs. 5.2. With so few samples and the variance among samples in each treatment, a much larger difference (about 1.1) would be required for statistical significance. Interestingly, results parallel those for plant cover: a slight but statistically insignificant advantage for the composted treatment. Results for functional groups are summarized in Table 2. The biggest difference was in free nitrogen-fixers.

Table 2. Microbial functional analysis in Reach A (n = 4 each).

Functional Group	Composted	Uncomposted
Aerobic bacteria	1.70	1.76
Anaerobic bacteria	0.78	0.66
Fungi	0.48	0.48
Actinomycetes	0.58	0.74
Pseudomonads	1.53	1.34
Free N-fixers	0.23	0.04
	-----	-----
Overall Rating	5.28	5.02

Not only did the composted and uncomposted treatments fail to differ significantly, but both had low diversity. BBC Labs set the upper threshold for low diversity at seven. It is a wonder that revegetation has so far been sustained at a satisfactory level considering the microbiological findings. Nitrogen fixation from inoculated legumes complicates this picture.

At CO 25 where compost was applied just one year before testing, the mean diversity rating for the composted floodplain was 4.53. In contrast, but not much contrast, the mean for four uncomposted samples was 4.45. If the soil at the slope (borrow area) is omitted because compost was irregularly broadcast and not really incorporated, the mean for three uncomposted samples along the old channel was 4.50. Obviously, there is no real difference. A breakdown by functional group follows in Table 3.

Table 3. Microbial functional analysis in Change Order 25 (n = 3 each).

Functional Group	Composted	Uncomposted
Aerobic bacteria	1.40	1.50
Anaerobic bacteria	0.50	0.40
Fungi	1.00	0.90
Actinomycetes	0.40	0.43
Pseudomonads	1.33	1.45
Free N-fixers	-0.10	-0.23
	-----	-----
Overall Rating	4.53	4.45

In Reach J, a single composted floodplain sample was compared to an uncomposted strip between two railroad tracks (Fig. 7). The hydrologic regime at both sites was judged to be sub-irrigated, but some streamflow from Silver Bow Creek flowed westward between the railroad tracks in spring 2010. The results once again showed low diversity in both cover-soils, this time with a slight advantage for the uncomposted dirt (Table 4).

Table 4. Microbial functional analysis in Reach J (n = 1 each).

Functional Group	Composted	Uncomposted
Aerobic bacteria	1.3	1.5
Anaerobic bacteria	0.7	0.5
Fungi	1.0	1.2
Actinomycetes	0.6	0.4
Pseudomonads	0.5	1.0
Free N-fixers	0.0	0.0
	-----	-----
Overall Rating	4.1	4.6

Figure 7. Two-year-old sub-irrigated revegetation in areas with (upper) and without compost (lower photo), Reach J, SSTOU.

Microbiology Results -- GSM

Recall that the hard-rock mine was included in this analysis to represent more difficult compost application and incorporation conditions associated with steep slopes. Five composted cover-soils were sampled and each result listed separately in Table 5 to show the range of values. Results at GSM were essentially the same as the more recent SSTOU revegetation, with mean microbial diversity in the mid-fours, again placing the amended cover-soil in the low diversity range. With compost application spotty and incorporation incomplete, one has to wonder whether the overall score of three for M4 isn't due to uncomposted baseline.

Table 5. Microbial Functional Analysis in Recent GSM Revegetation.

Sample/Functional Group	M1	M2	M3	M4	M5	MEAN
Aerobic bacteria	1.5	1.5	1.4	0.7	1.1	**1.4**
Anaerobic bacteria	0.2	0.3	0.5	0.2	0.2	**0.3**
Fungi	1.2	0.9	0.8	0.6	1.3	**0.9**
Actinomycetes	0.5	1.0	0.2	0.5	0.3	**0.5**
Pseudomonads	1.1	0.9	1.4	0.6	1.2	**1.0**
Free N-fixers	0.4	0.3	0.5	0.4	0.3	**0.4**
	-----	-----	-----	-----	-----	-----
Overall Rating	4.9	4.9	4.8	3.0	4.4	**4.4**

Summary

Neither soil microbiology nor vascular plant performance improved significantly by virtue of compost amendment. Nonetheless, most revegetation in the Silver Bow Creek project is meeting performance standards, and the temporal trend in perennial plant cover has been upward. Compost amendment was applied to all but a few spots. Given the general success of revegetation, perhaps the low microbial diversity provides an adequate degree of nutrient cycling, in which case we must conclude that uncomposted soil seems to be its equal.

Composted and uncomposted cover-soils have similar microbiological diversity as measured by BBC Laboratories. Some microbes in the compost, perhaps most, may have perished in the soil or survived only in the rhizosphere. Many thermophilic, hydrophilic microorganisms found in compost probably can't adapt to dry, often frigid soils of variable pH and a new array of food sources.

At GSM, all compost-amended cover-soils had low microbial diversity similar to the SSTOU. The collective results from both projects raises the question of whether introduced soil microbes drive revegetation or vice-versa, the vascular plants lead and soil microbiology follows. Soil biology may be one aspect of the recovery process that cannot be expedited using biologically active organic amendment.

The remaining possibility is that the essence of soil microbiology was not captured by the BBC laboratory protocol, or the bulk soil may not be the right place to look for relations of soil microbiology and plant health and productivity. Those activities may be confined to the rhizosphere, including mycorrhizae if present. The 1% of the soil volume that typically comprises plant root systems, and the associated rhizosphere soil, is a zone of intense change and activity in which the major part of soil nutrient cycling occurs. (Killham p. 79)

That evaluating microbiological activity is difficult comes as no surprise. What is surprising is that four laboratories characterizing common chemical parameters in two commercial composts could report wildly different properties. Lacking a unified laboratory protocol, uncertainty associated with “quantification” even of abiotic properties is large.

Other compost characteristics may be pertinent for particular uses. Nurseries have learned to their dismay that some compost products have enough pesticides from yard waste to kill plants grown in potting soil that has high compost content.

Literature Cited

Alexander, M. 1991. Introduction to soil microbiology. 2nd edition. Krieger Pub. Co., Malabar, FL, p384.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33(1):43-64.

Killham, Ken. 1994 Soil Ecology Cambridge Univ. Press 242 p.

Bob Linderman, personal communication

Prodgers, R. A. 2008. 2007 Revegetation and bird monitoring in portions of Subareas 1, 2, and 4. 32 p. + appendices.