NOTHING BUT BORROW – REVEGETATION WITHOUT TOPSOIL[1]

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Abstract: This project has been a grand field experiment in revegetating biologically inert coversoils with and without organic amendment. Seven years after seeding, the condition of revegetation in the area first seeded was evaluated, passing performance standards. Salvaged topsoil is generally considered the optimal revegetation substrate, but it is sometimes unsuitable or unavailable. This riparian Superfund project relied upon coversoils originating as deep, biologically inert borrow. Revegetation can be initiated on such substrates; the issue is permanence. To promote primary succession at an advanced stage, a variety of commercial compost products have been used as a coversoil amendment in the hope of establishing a soil food web and nutrient cycling. Compost provides a microbial community and a source of carbon and nutrients to sustain them until revegetation provides new substrates such as root exudates. Seven-year-old revegetation exceeded success criteria based upon perennial plant cover. The trend in plant cover from 2004-2007 has been slightly upward but dynamically constant despite declining legumes, suggesting a relatively smooth transition from legumes to other perennials. In a comparison limited in power by the small number of un-composted samples, plant cover did not differ significantly between composted and un-composted coversoils, although composted areas had greater mean cover. Applying too much wood-based compost induced in a few years severe infertility after the labile constituents were immobilized. Native species are not immune to the negative effects of reverse fertilization.

Additional Key Words: biologically inert coversoil, soil microbiology, compost, nutrient cycling, reverse fertilization, canopy coverage.

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Project Description

Superfund remediation of Silver Bow Creek in the county of same name in southwest Montana has so far entailed removing 2.8 million m^3 of fluvially deposited mine waste, reconfiguring the creek, and revegetating 384 ha (950 ac). Mine waste contaminated with heavy metals, mainly Cu and Zn, compounded by acidity was removed to safe repositories and replaced with coversoil.[1] (Suitable backfill criteria are in Table 2, Titan Environmental, 1997). Applied thickness following mine waste removal averaged 2 dm, varying from none to one meter with the thick application on just 0.8 ha.

For remediation purposes, the Upper Clark Fork River Basin watershed has been partitioned into several operable units; this one is called the Streamside Tailings Operable Unit (SSTOU). The geographic focus of this report, Reach A, was the first mile of stream and associated floodplain to be remediated. It was seeded and transplanted in spring 2001.

The paramount goal of revegetation is protecting the remedy (e.g., preventing erosion) and returning remediated areas to a permanent, productive condition. Permanence requires promoting soil genesis and nutrient cycling. Revegetation must be self-sustaining and self-repairing, although continuing noxious weed control has proven necessary. Restoration further creates an approximation of preimpact vegetation and soils while creating wildlife habitat for a variety of animals and providing aesthetically pleasing landscape components. Relative to the Record of Decision, two major improvements funded by the Natural Resource Damage Program (NRDP) restoration have been additional contaminant removal (in contrast to liming mine waste and leaving it in place) and providing organic coversoil amendment in a compost matrix.

At its simplest, remediation consists of removing contaminated mine waste and impacted soil to a safe repository and replacing it with borrow material, followed by seeding and transplanting. To a large extent, postremediation streambank elevation controls floodplain elevation. The stream must have sufficient gradient to transport sediment in order not to become a braided channel. Railroad bridges and other transportation features provide frequent elevational controls for the stream. Depth of removal varies from spot to spot based upon contaminant sampling. With mine waste gone, the floodplain elevation is set in relation to the relocated creek. The floodplain slopes toward the creek at a uniform grade of around one percent.

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[1] In this presentation, coversoil is a generic term for borrow material that is placed as a revegetation substrate as distinct from in situ substrates; it may or may not be amended.

Good sources of fill are scarce. At the base of the continental divide, nearby Butte, Montana, was once "the richest hill on earth" in local lore. Like most hard-rock mine settings, soils are mostly shallow over bedrock except for alluvial deposits, and alluvium below Butte consists mainly of mine waste. Clean fill near the floodplain consists of tertiary valley-fill deposits. Borrow areas, particularly in the lower reaches, have physical and chemical discontinuities, sometimes in close proximity.

In finding suitable borrow, construction constraints are imposed by distance, safety, and GVW limitations on public roads. The preferred approach is to build private haul roads from proximate borrow areas to destinations along the stream, which limits potential sources. Throughout the 35-km-long project area, coversoil particle size has ranged from gravelly sandy loams to silty clay loams. In Reach A, reported here, coversoils had (gravelly) sandy loam texture, mean saturation percentage of 37, pH 7, and electrical conductivity (EC) 5 dS/m. Underlying in situ material is typically gravelly (sometimes very gravelly or cobbly) coarse to loamy sand. The pH was circumneutral, EC averaged 2.5 dS/m, and saturation percentage was 32. Deeper material continued this trend with even coarser particle size, mean pH of 6.2, EC 1.7 dS/m, and mean saturation percentage of 24. In situ soils at the fringe of the floodplain were similar to subsoil described above.

This project has been a grand experiment in revegetating biologically inert coversoils with and without organic amendment. Mycorrhizal inoculants were not used as soil amendment, although many shrub transplant roots were inoculated. In spots, salinity and sodicity have been edaphic limitations where the soil moisture gradient is upward from underlying groundwater. It is impossible to distinguish the roles of coversoil and underlying substrate in providing salts via capillary rise. Less commonly, residual contaminants or acidity impaired revegetation. But permanently vegetating deep-borrow coversoils was the most prevalent challenge.

<u>Biologically Inert Coversoil</u>

Coversoil is transported borrow applied as plant growth medium. When a borrow area is opened, the surface 15 cm is scraped off and stockpiled for ultimate reclamation because the load of noxious-weed seed is typically so great that it is not desired in the floodplain. Depth of excavation is limited by borrow suitability and volume required within a practical distance; borrow deposits usually are underlain by lithic strata.

No doubt adequate plant cover can be established on biologically inert coversoil – initially. With chemical fertilizer providing at least 20 ppm mineral N plus P and K to redress deficiencies revealed by coversoil analysis, the initial flush of plant growth can be impressive – more so if flushed with desired perennials rather than ruderals and noxious weeds. The challenge is for revegetation to persist after the supplements end. In SSTOU revegetation, fertilization ends with the initial seedbed fertilization.

If the coversoil is not particularly saline, sodic, acidic, or contaminated with heavy metals, permanent revegetation is tied to nitrogen fixation or nutrient cycling. In coversoils lacking a reservoir of nutrients and nutrient cycling, revegetation can enter a downward spiral in which the nutrients in the soil are quickly tied up in living plant tissues and undecomposed litter. In cold environments, decomposition of dead plant material is a major restriction on nutrient mobility (Ziemkiewicz and Takyi, 1990). Decomposition is limited by low temperatures, drying of surface materials, low decomposer populations, and high C:N:P ratios. A decline in plant vigor often is accompanied by the accumulation of dead plant material on the soil surface. Assuming that the necessary microorganisms are present, a functional soil food web can be bottlenecked by insufficient carbonaceous substrates and nutrients for cell walls and metabolism.

Revegetating deep borrow calls for dramatically accelerating primary succession, that "ecological succession that first appears on a surface that has not been previously occupied by a community of organisms" (Gregorich and others, 2001). To meet revegetation objectives in a pragmatic time frame, that which is biologically inert must become biologically active. To that end, commercial compost was applied and incorporated to provide a source of carbon, nutrients, and decomposer populations that we hoped would function as a soil food web.

It requires a leap of faith to suppose that the microbial inhabitants of compost are suited to the substrates provided by young plant communities. Compost components can vary greatly, but the products used on the SSTOU usually include manure or sewage sludge, a carbon-rich component such as wood waste, and a green carbohydrate such as lawn trimmings, all digested in an aerobic, thermophilic reaction. The particular compost used in Reach A was very rich in organic matter (91% on a dry weight basis) due to a prevalence of wood waste products. However, this brought the dry bulk density down to 172 kg/m^3 (290 pounds/cu yd), so the compost application rate of 145 m^3/ha (77 cu yd /acre) was essentially the same as was calculated for the other two compost producers who bid that year.

Soil organic matter originates as root exudates, animal tissues and excretory products, and plant litter; it is a heterogeneous collection of substrates from which soil inhabitants 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, and exoenzymes for some substrates may be limited. The final steps involve only a few simple sugars and organic acids. There is a certain underlying unity in metabolic reactions (Alexander, 1991). It is this assumed unity of metabolic reaction that justifies amending biologically inert coversoils with compost to abet nutrient cycling.

Compost Amendment

This project probably was the first in the Upper Clark Fork basin to specify compost amendment. When Reach A was revegetated, two of three compost bids were <$100/metric ton, whereas in 2008 the lowest bid was $320/metric ton, indicating much increased demand.

Specifying compost attributes for procurement is difficult. Apart from the bare-bones requirements that it not contain excessive amounts of heavy metals, pesticides, or other contaminants, all SSTOU suppliers must comply with the US Compost Council Seal of Testing Assurance Program, which is a compost testing, labeling, and information disclosure program found at http://www.compostingcouncil.org/programs/sta/ . One empirical test we like is the "cucumber test" in which a cucumber (*Cucumis sativa*, no idea why this member of the Cucurbitaceae family was chosen) is grown in a 50/50 mix of compost and dirt. Vigor is ranked. Such a prevalence of compost would never be used in practice, and good vigor at least rules out phytotoxic agents such as herbicide residues. Otherwise, few requirements can be practically imposed without challenge from suppliers.

If an organic amendment was inert organic matter, it would be worth a fraction of the cost of compost, which has skyrocketed due to local reclamation demand. But while microinhabitants are critically important, their functional importance is difficult to evaluate. It does not help that microbiological laboratories use different criteria in evaluating microbial health, giving the appearance of arbitrariness or at least subjectivity.

Compost application rate was 1.5% organic matter by weight in the upper 15 cm (6 inches) (after incorporation) and now is 2% organic matter in the upper 10 cm (4 inches). Placing it deeper accomplishes little as biological activity there is strongly limited by lack of oxygen. A layer of compost typically about 2 cm thick, varying by product, is applied with a modified

Terragator or manure-spreader. Compost is disced in along with fertilizer. In calculating the amount and composition of fertilizer, the macronutrient contributions of compost are considered.

Compost bids are evaluated based on cost per unit mass of dry organic matter. This derives from information provided by bidders: wet (as delivered) bulk density (later verified by truck weights), percent moisture, and organic matter content, which is extrapolated by empirical constant from percent carbon. One unavoidable limitation is that the batch tested is rarely the batch later delivered.

In amending with compost, the assumption is that it introduces an incipient soil food web that can subsist on compost food stocks until revegetation establishes. When succulent plant tissues are introduced into the soil, the abundance of bacteria around and within subterranean substrates increases rapidly and dramatically. There is a concomitant rise followed by a subsequent diminution in the numbers of protozoa, the changes paralleling the bacterial fluctuations. Fungi and actinomycetes are much less affected. Mature crop tissues provide a different substrate and support of flora better adapted to resistant compounds – this population is largely fungal, although bacteria and actinomycetes are stimulated to some extent (Alexander, 1991). The flora concerned with humus breakdown differs from that associated with the breakdown of freshly added plant material. Microbial activity in SSTOU coversoils is often limited by lack of soil moisture and cold.

Seeding Materials and Practices

With several hydrologic regimes (a.k.a. soil moisture regimes) and significant differences in particle-size class as well as different seeding contractors/equipment, seeding techniques have varied, but a two-stage seeding is usually practiced with the heavy seed planted into the ground and the light seed subsequently applied on the surface. Nine different seed mixes of no particular relevance to the subject here were applied to different site types in Reach A, and some intereseeding mixes were applied the following year where revegetation lagged. Typical application rates are about 10 kg/ha of heavy seed and half that amount of light seed. The NRD program pays for “enhanced” seed to provide greater floristic and structural diversity than remediation requires.

Revegetation Performance

Monitoring Methods

Unless disturbances or replanting require modifications, monitoring measurements begin one full year after germination with subsequent measurements when the field reaches 3, 6, and 10 years of age. Sampling occurs in August. Since Reach A was seeded in spring 2001 and effectively germinated within weeks, it was 1 year old in 2002 when seedling density was measured and 6 years old in year seven (2007). At that time, it was compared to success standards (Table 1) because 2007 had approximately normal precipitation (Table 2), a requirement for this evaluation.

Table 1. Minimum Desired Canopy Coverage* Approximately 10 Years after Seeding in Years of Near-normal Seasonal Precipitation (MDEQ-NRDP , 2004).

HYDROLOGIC ZONE	AVERAGE PERENNIAL CANOPY COVERAGE
Uplands, Subirrigated	60%
Streambanks, Transition Zone	80%
Wetlands (not open water)	100%

* Not counting annuals or noxious weeds.

Table 2. Butte Precipitation Summary, 1964-2007.

YEARS	MAY-JUNE		PERCENT OF NORMAL	ANNUAL		PERCENT OF NORMAL
	cm	Inches	%	cm	Inches	%
1999-2004	9.4	3.7	86	26.9	10.6	84
2005	12.9	5.1	121	34.0	13.4	106
2006	10.9	4.3	100	31.7	12.5	99
2007	12.4	4.9	114	32.0	12.6	100
1964-2007	10.9	4.3		32.0	12.6	

Sampling methods for established revegetation combine two-dimensional canopy-coverage estimates from plots along permanent transects with shrub density measurements from a

1 m wide belt centered on the same transects. These methods have remained unchanged since monitoring began. This facilitates between-year comparisons, although precipitation must be considered, especially in uplands and the subirrigated zone, which are equivalent plant habitats except for deep-rooted species surviving long enough to exploit soil moisture one meter down.

Both measurements were sampled along 100 m transects unless a shorter one was required to fit within uniform habitats, e.g., to prevent crossing hydrologic boundaries. Transects 100 m long reflect average site and vegetation conditions within a significant portion of a hydrologic zone better than shorter transects that have a greater chance of emphasizing aberrations. Transect endpoints are located by GPS coordinates only, not physical structures. Thus, identical plot locations are not assured, just the same approximate areas. An unpaired t-test is appropriate for through-time comparisons, not the more powerful paired t-test.

Canopy coverage (Daubenmire, 1959) was estimated for each species in 20 0.5 m^2 plots at 5 m intervals along each transect with interval modification for shorter transects. Canopy coverage was estimated as accurately as possible; cover classes were not used. Stratified cover is reported, meaning that the coverage for each species is summed without regard for canopy overlap, so total cover can exceed 100%.

In 2007, Reach A revegetation was compared to success standards. The long-term monitoring plan states that "Remediation goals are fulfilled if canopy coverage equals or exceeds the goals set forth in Table 1 10, years after germination of the last seeding in years of near-normal precipitation. Normally distributed sample means will be compared to performance standards using the statistic described by Neter et al. 1985 with 0.1 Type 1 error and 90% of the performance standard" (MDEQ-NRDP, 2004). Another provision allows reaches that pass in year seven to be counted as successes without further monitoring; the intent was to prevent protracted sampling if year 10 did not have near-normal precipitation and the field already passed in year seven.

Results

Microbial populations of amended coversoils have never been assayed nor has a functional analysis been performed. Monitoring focuses on vascular plant cover and shrub density, but only canopy coverage is a success criterion. Since the oldest revegetation was just seven years old when last analyzed, trend is as important as quantity. Stratified canopy-coverage data reported here were taken from annual vegetation monitoring reports (Prodgers, 2002, 2003, 2004, 2007) that were included in interdisciplinary monitoring reports for the SSTOU.

In a semiarid environment, plant quantity and trend can only be evaluated within the context of annual precipitation, summarized in Table 2. Recent years have been normal to slightly above normal, which is distinctly wetter than the six-year period before 2005. Relative to the main comparison in this report, between 2004 and 2007, precipitation through July 2004 was 17 cm (6.8 in) vs. 20 cm (7.8 in) in 2007. *Ceterus paribus*, other things being equal, more plant cover would be expected in 2007.

Uplands and Subirrigated Zone. When Reach A revegetation was six years old (2007), mean perennial canopy coverage for all 15 upland and subirrigated zone samples was 68.1%. Since the mean exceeded the standard of 60% (Table 1), uplands and the subirrigated zone passed. Eleven of 15 individual transects passed (Table 3).

Table 3. Canopy-Coverage Summary for Reach A Uplands and Subirrigated Zone, 2007.

TRANSECT	HYDROLOGY	TOTAL COVER	PERENNIAL COVER*	STANDARD COVER	PASS?
1	Subirrigated	60.8	60.8	60	YES
2	Upland	104.6	97.8	60	YES
3	Upland	32.8	17.9	60	NO
4	Upland	73.7	69.5	80	YES
5	Upland	86.0	86.0	60	YES
6	Subirrigated	74.4	71.7	60	YES
8	Subirrigated	56.7	54.3	60	NO
9	Subirrigated	46.3	44.1	60	NO
10	Subirrigated	63.2	63.1	60	YES
11	Upland or Subirr.	69.8	69.6	60	YES
12	Upland	81.7	80.8	60	YES
13	Upland Repository	105.8	105.8	60	YES
14	Upland Repository	82.5	80.0	60	YES
16	Upland	52.5	49.7	80	NO
17	Subirrigated	71.9	70.1	60	YES
	MEAN	70.8	68.1	60	YES

*Noxious weeds, annuals, and nonseeded biennials are counted in perennial coverage.

Compost Field Test. As a control, compost was not added to coversoil in a designated portion of southwest Reach A comprising about one-fifth of the entire reach. Four of 15 upland/subirrigated transects were located there. In comparing coversoils amended and unamended with compost, in situ soils were deleted from analysis. Did compost confer advantage? The range of perennial cover in Table 3, from 18% to 106%, reflects variability in a host of substrate factors and virtually assured that a statistically significant difference would not be detected. Collectively, both treatments passed the perennial plant cover standard in Table 1. Using 0.1 Type I error and a two-tailed distribution, the confidence interval for perennial plant cover at uncomposted transects was 64.4 +- 18.1% vs. 72.0 +- 10.6% where compost was incorporated into coversoil. A paired t-test, had it been possible, might have provided a more definitive conclusion. The safest conclusion after six years is that satisfactory revegetation was prevalent in both composted and un-composted treatments (Fig. 1).

Another presentation in these proceedings showed that after one decade, certain spoil (another example of biologically inert borrow material) can support about as much plant cover as topsoil (Prodgers, 2009). Somehow biologically inert coversoils can function adequately at least in the 7-11 year time frame even without nitrogen fixation playing a major role.

Figure 1. Mean perennial plant cover was insignificantly higher in composted area on left than uncomposted areas on right. Both of these sites have subirrigated hydrology.

<u>Transition Zone</u>. The transition zone is named for the transition from subirrigated to wetland hydrology. The zone within 30 to 60 cm of the surface is usually aerated, but in average years it is saturated for at least two consecutive weeks in the growing season. Since the soil moisture

regime is wetter than the subirrigated zone, the plant cover success standard is higher (Table 1). Figure 2 shows Silver Bow Creek in Reach A and associated transition zone. No wetlands were sampled in Reach A.

Average perennial canopy coverage for the transition zone in 2007 was 89.8% (Table 4), so again the performance standard of 80% perennial plant cover was met directly without need for confidence interval. Three out of four transition-zone samples exceeded the standard. Total and perennial plant cover increased since 2004, when those values were 81% and 77%, respectively. However, the broad confidence intervals arising from great variability in plant cover among transects (Table 4) precluded statistical significance. One explanation for increased plant cover is that there has been some recruitment of non-weedy perennials, discussed next.

Figure 2. Reach A was the area of Silver Bow Creek and its floodplain first remediated. Seeding and transplanting was initiated in spring 2001. Every soil moisture regime from wetlands to coarse uplands is present.

Trends. In addressing permanence after seven growing seasons, the question of whether the revegetation trend is positive or negative is important. The slight upward trend (Fig. 3) is basically flat when precipitation is considered as discussed earlier.

Table 4. Canopy-Coverage Summary for the Transition Zone, Reach A, 2007. (Means and 90% Confidence Intervals.)

TRANSECT	HYDROLOGY	TOTAL COVER	PERENNIAL COVER	COVER STANDARD	PASS?
		--------------%---------------			
7	Transition	118.1	112.8	80	YES
15	Transition	85.7	77.1	80	YES
18	Transition	70.4	67.6	80	NO
19a	Transition	112.2	101.7	80	YES
	MEAN	96.6 +- 23.9	89.8 +- 22.4	80	YES

Uplands. Total upland/subirrigated plant cover in Reach A was 69% in both 2002 and 2004 compared to 71% in 2007. Perennial cover was 62% in 2004 compared to 68% in 2007, so the recent trend has been slightly upward, and 2.5 cm (one inch) of additional precipitation could easily account for the difference. (For example, the comparison for perennial cover, 0.10 Type 1 error, two-tailed distribution, is 62 +- 13% in 2004 vs. 68 +- 10% in 2007.) While plant cover increased, the average amount of bare soil exposed decreased from 38% to 23%.

Just maintaining the same amount of perennial cover is impressive given the recent decline, almost crash, of alfalfa and red clover in much of Reach A. Abundant legumes contribute importantly to high stratified (by species) plant cover (Table 3), e.g., >90%. Table 5 shows the dramatic decline at three transects that were selected to show how much legume cover has declined where once prevalent. While total cover declined 45%, alfalfa declined 55%. (That's 55% actual cover; the relative decline was 93%.)

Working with much heavier soils than ours, Reeder (1990) concluded that five years of alfalfa growth were sufficient to reestablish the rapidly cycling portion of the N cycle. We can only conclude somewhat tentatively that nitrogen fixation for a similar length of time has provided enough nitrogen to put revegetation on a satisfactory trajectory. With diminished nitrogen fixation, the cycling of nutrients in organic matter will be more important than ever.

The reason for the decline in alfalfa can only be speculated, but the slight upward trend in perennial cover for all transects against a background of plummeting legumes is reassuring. As legumes decline, they may transition more-or-less smoothly, yielding to grasses and other desired native perennials, or crash to be replaced with weeds. So far the former seems to be occurring.

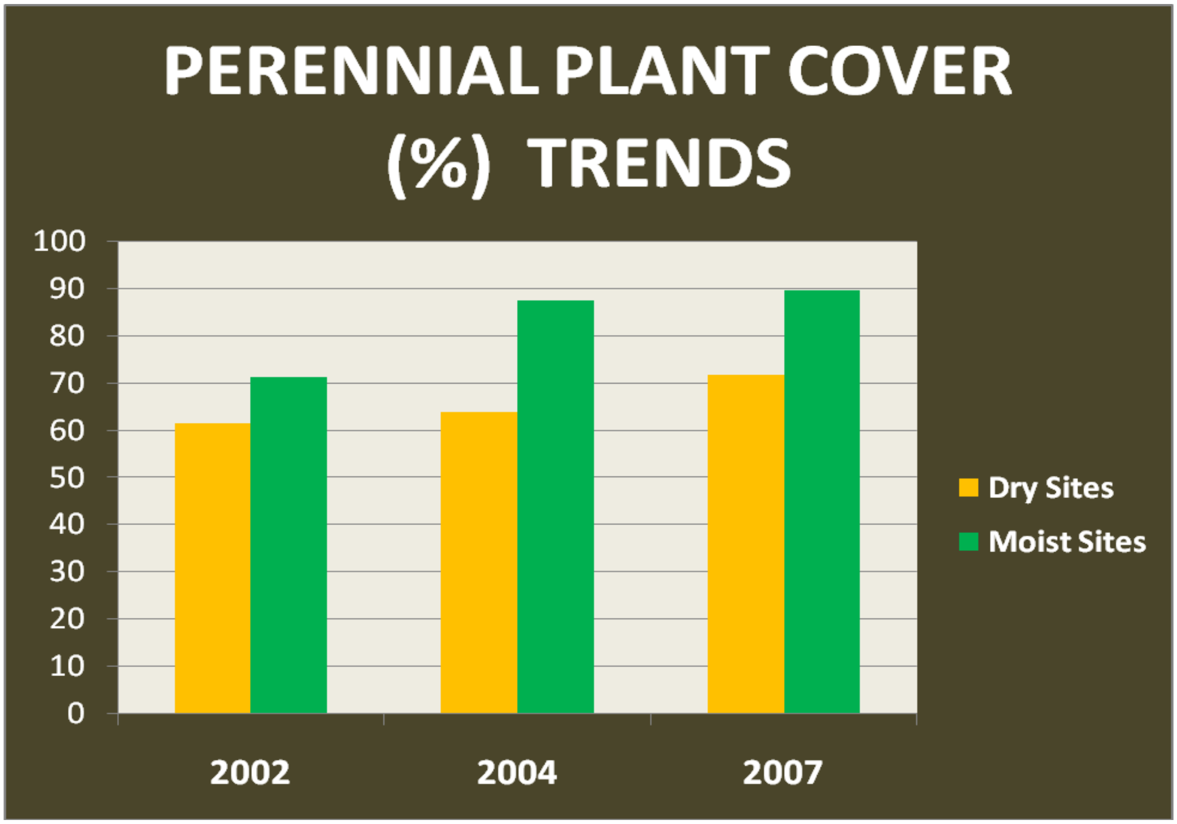

Figure 3. Trends in perennial plant cover in Reach A, SSTOU.

While cover declined dramatically in some uplands (Table 5), it increased greatly elsewhere. At Transect 13, the south face of the waste repository, total stratified perennial cover went from 51% in 2004 to 106% in 2007, mainly the result of enlarging rabbitbrush, the cover of which increased from 20% to 55%.

Table 5. Perennial and Alfalfa Plant Cover Trends at Three Sample Locations in Uplands, Reach A, 2004 and 2007.

TRANSECT	HYDR-OLOGY	PERENNIAL COVER 2004	PERENNIAL COVER 2007	ALFALFA COVER 2004	ALFALFA COVER 2007
		--------------------% Canopy Coverage-----------------------			
6	Upland	110	72	60	0
8	Upland	83	54	59	4
17	Upland	106	70	57	8
	MEAN	**100**	**65**	**59**	**4**

In seeding inoculated introduced legumes in revegetation, one knows they will not last forever, but they can confer important advantages that some consider worthwhile no matter how long they persist. Alternatively, incremental N fertilization might be required.

> *Additions of fertilizer N may, therefore, be needed to sustain plant growth until the system becomes self-sustaining…The principal requirements for a functioning system are a developed pathway of fast-cycling N and an input of N that is equal to or greater than the amount of N channeled into the soil organic matter (Reeder and Sabey, 1987).*

In uplands, nonseeded species were irrelevant to total plant cover given effective noxious weed control. Improvements resulted either from seeded species spreading vegetatively (e.g., rhizomatous grasses) or growing larger and seeding themselves (e.g., rubber rabbitbrush).

Transition Zone. The upward trend in perennial plant cover was more pronounced in the transition zone than in drier sites (Fig. 3). Rainfall has less of an effect in the transition zone than in uplands, so genuine improvement is likely.

Total transition-zone plant cover in Reach A was 92% in 2004 compared to 97% in 2007. Perennial cover was essentially unchanged, 87% in 2004 compared to 90% in 2007; comparing confidence intervals, a far larger difference would be necessary to detect a significant difference. Again, the safest conclusion is to accept the null hypothesis, plant cover was unchanged.

Several compositional changes have occurred in the transition zone. The legume dynamic, for one, is very interesting. Total legume cover declined from 47% to 38% from 2004 to 2007. Combined mean red and white clover cover declined from 20% to 3%. At the same time, bird's-foot trefoil cover increased from 27% to 35%. The lesson is, keep seeding trefoil; it seems to be the most enduring legume of moist sites. But keep seeding the clovers too – they play an important role in soil building even if transitional. Beyond the four transition-zone transects, white clover has persisted better than red clover, but red clover established more abundantly.

In moist sites, three nonseeded species increased perennial plant cover:

1) Most influential was Garrison creeping foxtail, the invasive, introduced grass that was deliberately seeded upstream in Lower Area One and continues to spread throughout the SSTOU. A few years after seeding, this rhizomatous grass, which is also a prolific seed producer, dominated streambanks, where it displaced native species. On some banks, it comprised more than 90% of plant cover. It also spread to areas of suitable hydrology away from streambanks, where it became locally prevalent. It spreads most readily

where plant abundance is below average, but like other invasive species, it can invade many plant communities if suitable habitat is present.

2) Second was foxtail barley, a native bunchgrass associated with moist, saline waste areas, and drawdown zones. While this grass is usually considered undesirable, the additional plant cover was welcome.

3) Creeping bentgrass is a naturalized sod former classified as introduced in the lower 48 states, Canada, and Alaska by the USDA-NRCS Plant Database. It is very widespread but ranks third among the moist-site volunteers along restored Silver Bow Creek. It is rhizomatous, metal tolerant, and common in both contaminated and uncontaminated riparian zones locally.

Some new weeds appeared in Reach A by 2007. Most abundant were spiny sowthistle (*Sonchus asper*, an annual) and moist sowthistle (*S. arvensis*, a perennial), which are present in portions of the transition zone. Some seeded species, such as black greasewood, declined over time.

Effects of Doubling the Compost Application Rate.

A compost supplier urged that 2% organic amendment to the upper 10 cm (four inches) of coversoil was insufficient to provide optimal benefits. A field test was implemented applying twice the usual rate (i.e., 4% organic matter in the upper 10 cm) in two similar areas, each receiving a different brand of compost. Both composts were wood-based. I predicted that once the labile constituents were gone, the carbonaceous substrates would comprise a nitrogen sink, i.e., nutrient immobilization or “reverse fertilization.” But vendors can be persuasive, and the heavier compost rate was tested. The rest of that reach received the normal amount of compost from one of the two suppliers.

Revegetation established so poorly on one test area that it was disced and reseeded, another grand experiment foiled. The other area with 4% OM in the upper 10 cm using the product described under Project Description and used elsewhere in Reach C started magnificently from its fall 2002 seeding. For reasons unrelated to this topic, canopy coverage sampling was delayed in that reach, but in 2003 it had 3.4 grasses, 1.4 forbs, and 1.4 shrubs per 30 cm^2 (square foot) for a total of 6.2 perennials per 0.93 m^2 with 100% frequency. Such a density cannot be sustained in the subirrigated zone, but it was far better stocked than other subirrigated sites and suggest that more compost conferred initial advantage. The most obvious reason is that the upper soil initially received twice the mineral nutrients from compost. The best transect in an area receiving the normal compost rate had a total of 2.5 perennials/0.93 m^2 with 58% stocking, and most of the other transects had between one and two seedlings per 0.93 m^2.

Shrubs were mostly big sagebrush with <10% rubber rabbitbrush. In the next few years, I noticed that sagebrush was growing much slower than normal, and in 2005 most plants remained less than one dm tall. When Reach C was first sampled for cover and shrub density in 2007 along the same transects previously sampled for seedling density, total and perennial plant cover were below average. Field notes from sampling reported:

Diminished cover and shrub density, visible effects of infertility in grasses, small rubber rabbitbrush, and litter buildup. Most sagebrush has died since last year. Seeded plants are more verdant and vigorous near volunteer sweetclover, that too being a manifestation of infertility.

Sagebrush density plummeted from about 42,000/ha to about 100/ha. Overall appearance was that of pestilence (Fig. 4). Most of the canopy coverage came from thickspike wheatgrass (*Elymus lanecolatus*) with rubber rabbitbrush (*Ericameria nauseosa*) and western aster (*Symphyotrichum chilense*) subdominant. Western aster is a stress-tolerator, and rabbitbrush does well on coarse infertile substrates by virtue of extensive, fairly deep root system.

Figure 4. After four years, the area in Reach C with twice the normal amount of compost lost most of its rhizomatous grass (left photo) and big sagebrush density plummeted from 42,000/ha to 100/ha. Due to severe N infertility, it became ripe for sweetclover invasion on right.

The suggestion that wood-based compost can induce severe infertility was collaborated by sparse, stunted vegetation where compost stockpiles were once located (Fig. 5). Applying inorganic N fertilizer dramatically increased plant abundance the following year, but negative effects such as the loss of big sagebrush could not be undone.

Figure 5. Stunted bunchgrasses at a previous compost stockpile location in Reach B gave an obvious clue about the nutrient impoverishment effect of too much wood-based compost. Photo on right shows same site one year later after inorganic fertilization, mainly N.

Summary and Conclusions

Silver Bow Creek remediation entails removing mine waste, relocating the creek, and bringing the floodplain to grade with biologically inert borrow, which when placed is called coversoil to distinguish it from real soil that has previously supported plant life. Roughly three-quarters of coversoils in the first reach of remediated Silver Bow Creek were composted. Seven years following seeding, both composted and uncomposted areas exceeded revegetation performance criteria. While there are convincing reasons to expect organic amendment of biologically inert coversoils to confer important benefits to revegetation, such benefits did not support significantly greater plant cover in a field comparison limited by high variance and small sample number in the uncomposted treatment. While mean cover was higher where compost was applied, the most striking result is that after seven years revegetation developed satisfactorily without organic amendment. Compost may provide other benefits, such as complexing heavy metals and salts and ameliorating crusts. Applying too much wood-based compost can induce severe infertility after several years to which native species are not immune.

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