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EVALUATION OF SOIL RESOURCES FOR SUSTAINED VEGETATIVE COVER OF CUT-SLOPES ALONG I-70 NEAR STRAIGHT CREEK

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16. Abstract
Revegetation of high elevation decomposed granite cut-slopes often requires repeated applications of soil amendments to attain sustained vegetative cover. Plant transects from slopes west of the Eisenhower Tunnel from 2007 to 2012 showed that cover was generally stable during this period. Soil fertility tests indicated that nutrients are generally low but still comparable to disturbed-but-revegetated reference plots. Soil organic matter and slow-release forms of nitrogen (N) may be a potential limiting factor. The N release rates of several common CDOT soil amendments were evaluated in a multi-year, field incubation experiment. Test results indicate a wide range of N release availability from nearly immediate to fairly slow release rates. Of the slow-release materials, about 74 % of total N content was released the first growing season, another 7 % in the following two years, while about 19 % was still retained in a more stable organic matter form at the end of the experiment. The study suggests that after several applications of slow-release amendments, vegetative cover on these cut-slopes is stabilizing.

Implementation
Slopes that show signs of vegetation thinning should be re-amended promptly with modest amounts of slowly available N. Established stands or sites with more moderate growth conditions may be able to take up much of the available N from larger applications of these slow-release amendments. But on newly seeded sites in high elevation conditions with slow growth potential, the plants may not be large enough to capture N as it is released. An amendment with high carbon such as wood chips or shreds may immobilize excess N by incorporating it into microbial biomass as the mulch degrades. This mulch layer would also help retain organic duff to rebuild the soil. Combinations of existing organic amendments may provide slower, more long-lasting N release. Development of a soil test to specifically measure slowly releasing organic N would improve monitoring and management of erosive slopes.

17. Keywords
Interstate 70, revegetation, native plants, soil amendments, soil fertility, nitrogen (N) release, erosion control, cut-slopes, decomposed granite (DG)

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EXECUTIVE SUMMARY

High elevation cut-slopes often are difficult to revegetate because of harsh growth conditions and poor soil development. This report summarizes a study to evaluate the status of soil fertility and revegetation cover of decomposed granite (DG) cut-slopes along west-bound I-70 just west of the Eisenhower Tunnel. It also includes the results of a field experiment that evaluates nitrogen (N) release from revegetation soil amendments.

Revegetation cover and soil fertility were measured from twelve permanent plot locations established in 2007 and remeasured in 2008, 2009 and 2012. Measured nutrient levels in these soils were in the ‘low’ range of standard soil fertility tests but they are not generally deficient for native plants in comparison to disturbed-but-revegetated reference soils, other than having low soil organic matter and low nutrient retention capacity. Plant transect data results do not indicate an overall trend of declining plant cover at these sites during the study period. The lowest vegetative cover was measured in a drier than average year. Animal burrowing activity strongly impacted measured cover on some transects. In general, current soil amendment application practices appear to be maintaining revegetation cover in these slope conditions at this time.

Because of this finding, and to better understand the effectiveness of several commonly used CDOT soil amendment materials, the project scope was modified to include a field experiment to measure long-term nitrogen (N) release. This second objective was addressed using field incubation columns loaded with soil amendments that were mixed with coarse decomposed granite substrates from the project slopes. Soil amendment materials are Gro-Power (G), Biosol (B) and Biosol with humate (H). Columns were installed in Fall of 2008 and sampled Spring and Fall of 2009, Spring and Fall of 2010, Spring of 2011 and early Winter of 2012, or approximately twice per year. Spring-sampled tubes represented nutrient release during winter with cold-season and early spring growth conditions and snowmelt runoff events. Fall-samples represent summer growth conditions with warmer temperatures, higher biological activity and summer rain.

Evaluation of extractable nutrient release (soluble ammonium and nitrate) from the selected soil amendment materials shows large differences in N release rates. The most rapid N release rate

came from soil amendment material G. In the very first wet-up period, it released approximately 83% of the extractable N delivered throughout the whole measurement period.

The B and H amendments contain much more of their fertility as organically bound N, which is more slowly released through microbiological decomposition. Only about 6 or 7 % of the extractable N from these materials was released during the first wet-up period, which limits leaching losses. Through the rest of the first growing season approximately 70% of all of the extractable N through the study is released. On the basis of measured total N levels of organic residues in the experimental substrates, 58 % of the amendment N applied appears to be released in the early in the first growing season (spring, early summer). By the end of the first summer, another 16 % had been released from the total N pool in the columns. Another approximately 7 % is released in years three and four after application. Approximately 19 % of the applied total N in the amendment remains as a persistent organic residue after three years. The stability and release rate of this stable pool have important influences on future revegetation performance of a site but were not measured as part of this study.

Implementation

If harsh sites start to lose plant cover or increase sediment losses, amendment reapplication should be made promptly to sustain vegetation cover and soil organic matter rather than allowing cover to thin and then trying to rebuild the site after erosion has increased. Repeated reapplication of the B and H treatments is expected to have cumulative beneficial effects on these steep, erosive substrates in part because of the residual stabile organic matter. For slow growth conditions, a mixed application of high carbon material (wood chips or shreds or hydromulch) at the time of soil amendment is a way to re-incorporate released N into new organic compounds, slowing down the net loss of N. The amounts and timing of coarse woody / soil amendment blends depends on how fast the wood decomposes (type and particle size), and site temperature, moisture and fertility conditions. Management of these harsh sites would be improved if a soil test were developed that specifically indicates the size and quality of stabilized organic matter in the soil. The test should evaluate the amount and rate of slow, sustained N release of ambient or amendment additions. This type of information would increase monitoring effectiveness of large, erosive cut-slopes and would improve the accuracy of maintenance responses if or when amendment was needed.

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INTRODUCTION

Disturbed slopes along the high elevation sections of the I-70 corridor in Colorado have been observed to revegetate following amendment and seeding, but plant cover is sometimes sparse. Further, a trend is observed in which the cover thins over a 10 or 15 year period, leaving the slope bare and erosive. A preliminary suite of soil sampling and testing of unvegetated substrates along the I-70 corridor west of the Eisenhower Tunnel indicated that these materials are not toxic to plant growth but they were generally low in nutrients. Soil organic matter content and extractable nitrate-nitrogen of the unvegetated areas were a quarter to a half the amount in the subsoil and topsoils of undisturbed and well vegetated areas. Phosphorus on the revegetated sites is about half of the undisturbed vegetated areas. This suggests that these substrates are marginal for support of plant growth and that retention of amended nutrients is insufficient, as shown by the gradual decline in plant growth after the initial amendment and establishment. Field conditions such as these can be solved several ways: by more frequent application of amendments, by application of longer-lasting amendments, by increased retention of added nutrients, or by increasing the ability of the soil to cycle nutrients between plants and soils and back to new plant growth. This project involved an initial scoping phase of soil conditions. It was later re-directed to involve a long-term evaluation of common nutrient amendments, especially the nitrogen release patterns over a several year period.

To address the problem of declining revegetation cover on these harsh sites, field substrate conditions need to be characterized. In addition, the basic components of soil-plant nutrient cycling processes need to be kept in mind, especially for a rapidly cycling and essential element such as nitrogen (N). The ability of a soil amendment to provide plant-available N in sufficient amounts and longevity to support sustained plant growth typically involves several different interacting nutrient compartments, or pools. An existing and functioning natural soil, for example, provides a large pool of stabilized soil organic matter (SOM) that slowly decomposes to recharge a smaller, transient pool of extractable, plant available nitrogen. Since the revegetated slopes appeared to have lower levels of soil organic matter by half, soil amendment is often needed to supplement a chronically low level of N for regeneration of vegetative cover.

An additional issue is how long the available N from the amendment lasts in field conditions. In a previous study, a variety of fertilizer materials ranging from soluble chemical forms to formulated slow-release forms to organically compounded materials were evaluated for the relative rates of N release for plant growth. Examples of these N release rates were from laboratory incubation columns and presented in Appendix A. The general groups include chemical formulations with soluble compounds or encapsulated prills (groups 1 and 2), defined organic materials that release N by microbial decomposition (group 3), and organic byproducts such as green waste composts (group 4). N release rates vary from nearly complete release upon wet-up (group 1, ammonium phosphate chemical, AP) to slow-release rates lasting many months or years (group 4, greenwaste composts (GC)). By contrast, native soil organic matter on which plants typically grow has N release rates of about 1 to 2 % of the total N content per year, providing a reserve of several decades of N for support of plant growth. Because these stable soil organic matter pools are relatively large in size, they can continue to supply plant growth needs for many years because of their relatively slow rate of decomposition and N release. The previous study was done in favorable temperature and moisture conditions in the laboratory. However, this type of release rate information has not been measured in high elevation, coarse textured substrates with the widely varying temperature and moisture conditions typical of cut-slopes along the I-70 corridor near Straight Creek and the Eisenhower Tunnel. Information on the functional release rates in field conditions will improve interpretation of current CDOT amendment practices and outcomes in these mountainous conditions.

The objectives of this proposal were 1) to evaluate the plant cover, soil type and nutrient characteristics of re-vegetated soils along cut-slopes along I-70 near Straight Creek; and 2) to evaluate the rate of N release from three commonly applied soil amendments in this area. These two analyses were then be used to interpret the efficacy of current reapplication practices of soil amendments to avoid loss of vegetation cover. Proposed plots along the I-70 cut-slopes were located between the Eisenhower Tunnel and west to the emergency truck ramp at mile post 212.0.

METHODS

Revegetation history

Slopes in the general project area have received several previous revegetation efforts to correct poor vegetative cover following construction (Figure **1**). Information on previous applications was provided by CDOT staff from job sheet records and plans (pers. comm. Tyler Weldon, Design Engineer, R1 Mountain Residency, Project Team 6, Nov 2012). These records indicated that in 2000, cut-slopes from Mile Post 210.0 to 213.3 received rock scaling, seeding erosion control mulch (CDOT project 12399). The seed was applied at 63#/AC, Humate 1500#/AC., Biosol 2000#/AC and 76#/AC of potassium with two tons of hay mulch per acre.

Figure 1. Unvegetated slope soon after construction before erosion control and revegetation treatment (T. Weldon, CDOT photo).

Seed was specified to be source-identified, including the elevation, county and state where collection was made. Collection source is restricted to +/- 1000 feet in elevation of the project site and within Colorado, Utah or. Seed, mulch tackifier, humate, azo-cote and organic fertilizer shall be applied in a single hydraulic slurry application per project special provision 212. A seed list is presented in Table 1.

Table 1. Seed specified for Straight Creek revegetation jobs. Source file: 2991 IM 0703 250; 12399 I70 Straight Creek Slope Rehab.pdf, sheet # 18.

COMMON NAME	BOTANICAL NAME	POUNDS PLS/ACRE
Slender wheatgrass v. Pryor	Elymus trachycaulus ssp. trachycaulus	8.0
Streambank wheatgrass v. Sodar	Elymus lanceolatus ssp. riparium	7.0
Western wheatgrass v. Rosanna	Pascopyrum smithii	7.0
Mountain brome v. Bromar	Bromus marginatus	5.0
Canada bluegrass v. Reubens	Poa compressa	2.0
Alpine bluegrass	Poa alpinum	2.0
Timothy	Phleum pratense	2.0
Red fescue	Festuca rubra	4.0
Meadow foxtail	Alopecurus pratensis	6.0
Rocky Mtn. Penstemon	Penstemon strictus v. bandera	1.0
*Potentilla	Potentilla fruticosa	2.0
Alsike clover	Trifolium hybridum	4.0
*Woods rose	Rosa woodsii	2.0
Strawberry clover	Trifolium fragiferum	3.0
Sheep fescue v. Covar	Festuca ovina	5.0
Showy Goldeneye (scarified)	Viguiera multiflora	2.0
*Lodgepole Pine	Pinus contorta latifolia	1.0
TOTAL		63.0

In 2002, poorly vegetated slopes from MP 207.3 to 210.9 were seeded (project 13751). This area is generally west of the current project site although the job did include one area (#27) at MP 212-212.8 to correct a slope problem. The mile post numbers indicate that this area includes the plots R5, R6, R7, and R8 of the current project. The 2002 project involved two applications in the Fall and one in the Spring. It used 52 lb/ac seed, 1000 lb/ac humate, 2000 lb/ac Biosol and 60 lb/ac potassium with 2 tons/ac weed free mulch per application.

In 2005 another erosion project addressed some drainage improvements and revegetation around the tunnel parking area but did not seed the slopes where plots for the current study were located. In 2009 another erosion project put in some clean water diversions but again no additional seeding. However, plant transects evaluated as part of this study in 2009 recorded heavy hydromulch application at Mile Post 213.0 (V3 and V4). It is not known whether this was an overspray issue or if the area was fully retreated as a spot erosion control treatment.

Study plot locations

Plot locations for this study were identified in collaboration with CDOT staff. The objective was to find cut-slope areas that represented revegetation problems for maintaining plant cover. Because the area is at high elevation and has harsh growth conditions, conventional erosion control stands and standard agronomic targets for soil fertility may not be representative. Instead, a local set of 'disturbed-but-revegetated' reference sites is used for comparison. This term means that soils may have been disturbed by grading but that most of the natural soil materials are still present; only the vegetation has been removed and regrown. These slopes tended to be in areas where the natural slope grade received only minor grading and the original forest cover was removed and represent an achievable level of revegetation in these environmental conditions. Cut-slope plots with harsher conditions were selected from different large, deeply excavated areas that currently ranged from well vegetated to low vegetated to slopes with thinner cover.

A total of 12 plots were selected with eight plots representing the range from low or adequate cut-slope vegetation (labeled 'V') and four representing the reference disturbed-but-revegetated conditions with native soil ('N') (Table 2). All sites were south facing, steep (30 to 38 degrees above horizontal) on the north side of west bound I-70 west of the Eisenhower tunnel. Plots were located above the sand line formed from snow blowing equipment and residual road sand deposits.

Table 2. Plot locations.

Plot locations by plot type				slope angle
Type	Mile Post	Station #	comment	(degrees)
Native reference sites				
N1, N2	212.8	385.5	disturbed but soil in place	35
N3, N4	212.0	340.0	disturbed but soil in place	30
Revegetation cutslopes				
V1, V2	213.6	415.0	medium cover, nearest tunnel	37
V3, V4	213.0	385.5	lower cover, near safety sign	35
V5, V6	212.8	385.5	high cover, seep area near exp	37
V7, V8	212.5	380.1	medium cover, aspen plots	38
Plot locations by location				slope angle
Type	Mile Post	Station #	comment	(degrees)
V1, V2	213.6	415.0	medium cover, nearest tunnel	37
V3, V4	213.0	385.5	lower cover, near safety sign	35
N1, N2	212.8	385.5	disturbed but soil in place	35
V5, V6	212.8	385.5	high cover, seep area near exp	37
V7, V8	212.5	380.1	medium cover, aspen plots	38
N3, N4	212.0	340.0	disturbed but soil in place	30

Each plot measured 3 meters (10 feet) across the slope on contour and 5 meters (18 feet) on the slope fall line (up and down slope). The corners of the rectangle were marked with wooden stakes. Three randomly positioned transects were located across each plot on the contour across the 3 m distance. Plant cover was estimated by point intercept method at 0.1 m (4 inch) intervals along the transect, starting with a 5 cm offset from the west side to clear the stake. This provides a total of 30 measured points per transect or 90 points per plot. Plant cover values for each set of three transects per plot were combined as a single average value. At each location, cover was tallied into the following categories: 1) dirt (< 2 mm fine soil plus gravels up to 10 mm); 2) rock (>10 mm); 3) grasses; 4) forbs. These four groups were graphed for Native soil sites and Revegetation sites, along with total plant cover amounts derived from these data.

Plot photos

Figure 2. Native soil plots N1 and N2 on the shallow slope of a graded access ramp running from center right to upper left. There was native soil on this area of the site, although it had been disturbed by grading. Plot N1 was located behind the conifer on the slope edge and plot N2 was located just left of the dead snag at the slope edge in the upper left of the photo. Revegetation plots V5 and V6 are located on the cut-slope face just below the single conifer at the slope edge, as delineated by rows of stakes on the plant transect ends and the plot corners. Photo from 2008.

Figure 3. Native soil plot N2 in 2008 near dead snag.

Figure 4. Native soil plot N2 in 2012. Transect stakes can be seen in the photo center at the end of the tape and near the upper rock berm. Tree removal activity disturbed the area prior to 2012 sampling.

Figure 5. Native soil plots N3 and N4 are located in the lower right corner of the large clearing to the right of the cantilevered sign structure.

Figure 6. Native soil plot N3 showing transect stakes on contour plus a corner stake to the upper left.

Figure 7. Revegetation plots V1 and V2 in right center of photo. This is the slope nearest the tunnel parking area.

Figure 8. Close-up of Revegetation plot V1 and transect. 2008.

Figure 9. Close-up of Revegetation plot V2 transect near the start of the study in 2008.

Figure 10. Close-up of Revegetation plot V2 transect at the end of the study in 2012.

Figure 11. Revegetation Soil plots V3 (far right) and V4 (center) showing lower cover. 2008.

Figure 12. Revegetation plots V7 and V8. 2008.

Figure 13. Close up of Revegetation plot V3 at the start of the study in 2008.

Figure 14. Revegetation plot V4 at the end of the study in 2012. Sign has been updated.

Statistical analyses (analysis of variance with mean separation by Fishers LSD) were performed on each cover type across the four years that data were collected. Each plot (all three transects combined) was considered an experimental unit. Native plants had n=4 and Revegetation plots had seven or eight replicates (one set of plots could not be located for one time point). An original intent was to have examples of high, medium and low cover in the Revegetated category, but the distinctions in the field were not clear and changed between years. Instead, the whole set of Revegetated plots was treated as a single group and contrasted between years, as was cover from the Native Soil plots.

Amendment materials for nutrient release trials

Given the low organic matter content of the DG substrate, plant available N was also expected to be low. New CDOT projects typically utilize several forms of slow release or organic soil amendment materials. A field incubation column experiment was designed to estimate how fast these soil amendment materials release N for plant uptake and growth.

The fertilizer release experiment contained four treatments. The ‘zero control’ tubes contained only straight DG material from the cut-slope surface. Three other treatments tubes included one of the organic soil amendments described below:

G treatment: Gro-Power (http://gropower.com/product_pages/gp_product.htm accessed June 25, 2012). Listed as ‘5-3-1 NPK analysis, 70% Humus, 15% Humic Acids, Micronutrients, and Soil Enhancers.’ Nitrogen (available) 5.00%, Phosphate 3.00%, Potash 1.00%, Humus 70.00%, Humic Acids 15.00%. Gro-Power bacterial "stimulator" included. Recommended application rate 150 – 200 lb per 1000 sq. ft (equivalent to with a recommended application rate of 6534 - 8712 lb per acre).

B treatment: Biosol (http://www.rockymtnbioproducts.com/biosol.htm accessed June 25, 2012). Listed as N-P-K 6-1-1 Organic – all-purpose fertilizer. Organic Matter > 85%, Carbon/Nitrogen ratio near 6:1, Nitrogen (total) > 6%. Nitrogen (water soluble) <0.5%, Phosphorus (P_20_5) 1–2 %, Potassium (K_20) 1%, pH level of 3.6 – 4.5. Recommended application rate of 500 – 2000 lb per acre depending on soil conditions and plant types.

H treatment: Humate amendment (http://www.rockymtnbioproducts.com/humate.htm accessed June 25, 2012). Similar to Biosol amendment above with the addition of Earthgreen Menefee Humate All Natural Organic Soil Conditioner listed as 50 % humic acids, 1 % nitrogen (N), <

0.1 % phosphate (as P2O5), < 0.1 % potassium (as K2O), 1.04 % calcium (Ca), 0.18 % sulfur (S), 0.14 % magnesium (Mg), 0.3% iron (Fe), 0.0004% manganese (Mn), 0.0002% copper (Cu), pH 3.4.

Experimental field incubation columns

Replicated experimental field incubation tubes were constructed out of 2 inch PVC pipe (43 mm diameter x 300 mm long) with nylon screen (3 mm; 1/8 inch mesh size) welded across the bottom (Figure 2). Each tube was loaded with 4 different horizons. The top soil horizon was started 50 mm down inside the tube to prevent disturbance by elk, which have been observed to grub and eat some of the organic amendments after application. The top of three substrate horizons was a 25 mm thick layer of coarse, washed pea gravel (screened to 8 to 10 mm; 1/2 inch mesh size) that was intended to prevent rain drop splashing from one tube to the next and to discourage burrowing animals and germinating seeds. Beneath the gravel layer was a 50 mm (2 inch) thick 'amendment' horizon. This material consisted of clean screened (< 2 mm) matrix decomposed granite material excavated from a barren area of the cut-slope that had low plant cover and low organic matter content. This matrix material was dried and screened to < 2 mm particle size, mixed well and then amended with appropriate amounts of the three amendment types. Amendment types are coded for presentation: GroPower (G); Biosol (B), Biosol plus humates (H). The zero control (Z) was loaded without amendment. Under the amended layer was a 125 mm thick horizon of the same clean subsurface matrix that served as a 'subsoil' substrate that could be sampled to evaluate leaching losses. Finally, the bottom layer was 20 mm of clean, washed quartz sand with a 1 – 2 mm particle size distribution that allowed water flow to the underlying soil and prevented a perched water layer at the bottom of the tube. Each individual horizon was separated by a close fitting round circle of nylon screen mesh that helped with identification and recovery of the separate horizons when each tube was collected and harvested for analysis, as described below.

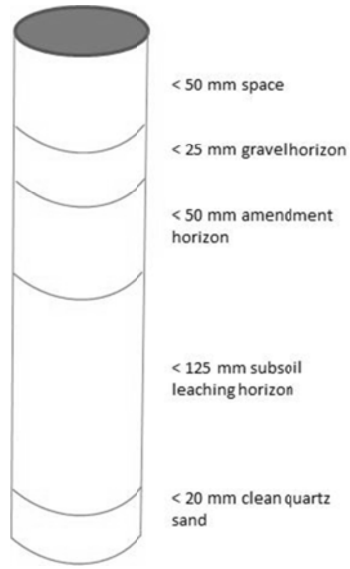

Figure 15. Field incubation tube showing amendment and subsoil horizons (50 mm x 300 mm; 2 x 12 inches) with each horizon separated by a (3 mm; 1/8 inch mesh) nylon screen.

Loading: The Biosol treatment (B) was loaded at a rate equivalent to 2000 lb product per acre on a surface area basis. The humate treatment (H) was in reality a Biosol + humate amendment. It consisted of the same Biosol rate (equivalent to 2000 lb product per ac) plus the humate amendment equivalent to 1500 lb product per ac. The Gro Power treatment (G) was loaded to contain the same total nitrogen content as in the Biosol and Biosol + humate treatments. The amendment load was calculated using the 5 % N listed for the GroPower product. Because the soil 'depth' was less in the incubation tube than in the field soil, the concentration was higher in order to approximate the per-area application rate.

Figure 16. Overview of fertility release experiment site at mile 212.8 on graded access ramp.

Figure 17. Overview of fertility release incubation columns during construction. Tubes left in the field were placed with tops level to the ground surface.

Sample collection and timing: All data graphics for extractable N, total C or total N have the same X axis showing sampling time as well as year and sampling time. 'S' indicates 'Spring,' 'F' indicates 'Fall' and 'W' indicates 'Winter' harvesting time. Except for the last sample interval, samples were pulled soon after final spring snow melt-off and just before the first accumulation of snow in the fall. Although the specific times varied by year, they were typically sampled at approximately 6 month intervals. The # 7 time point tubes were pulled in early March, 2012 after 9 months, as a final sampling time.

On the Y axis, the ‘0’ sampling point represents the ambient condition of the DG substrate before amendment. The ‘1’ time point shows the extractable N of the amended substrate at the time of installation in the field without any exposure to rain. These samples were taken to the field and immediately returned to the lab for analysis. These samples represent the ‘as-built’ or ‘as-amended’ condition. The subsequent sampling time points (2 through 7) are labeled with the season and year of the time when the sample tubes were pulled from the field.

Sample collection occurred approximately twice yearly. Analysis consisted of excavating each horizon from the tube sequentially and air drying at 60 °C within two days after the tube was collected from the field. These were then stored in a desiccated container at 4 °C environment until analysis. Analysis consisted of extraction with 1 M NaCl for plant available ammonium and nitrate and colorimetric analysis of N (Doane and Horwath, 2003). Total N and total C were analyzed on ground samples (< 150 um) by dry combustion on a Costech CHN elemental analyzer (ECS 4010 CHSNO, Costech Analytical Technologies Inc. Valencia, CA).

RESULTS

Weather patterns during project period

A summary of some relevant weather data from Silverthorne, CO is included in Table 3 for the project period. This time interval includes the years of initial revegetation amendments in 2000 through the last field incubation column harvest in 2012.

Several notable events that may influence interpretation of revegetation trends include a heavy rain period in April of 2000, which may have preceded seed and hydromulch application. The remainder of the year had above average precipitation. During our plant transect data collection, the 2007 and 2008 years had above average precipitation, followed by below average precipitation in 2009 and 2010. Low grass cover may be attributable to this decrease in precipitation. The final two years before the 2012 transect analysis were wetter than average for this period. One larger storm occurred in July 2011 that delivered 1.78 inches in a 24 hour period.

Table 3. Weather comparisons for the general survey area from 2000 through 2012 from Dillon/Silverthorne, CO. Columns show Year, followed by average maximum summer temperature, followed by total precipitation per year. The fourth column shows departure from this 12 year average, followed a column showing maximum 24 hour rainfall per month that exceeded 0.5 inches.

Year	average max+ summer temp (°F)	average annual ppt (inches)	departure from average (inches)	max 24 hour precipitation++ (events per month > 0.5 inches)
2000	73.8	15.52	+1.10	1.34, 0.57, 0.56, 0.57
2001	73.3	12.82	-1.60	0.61, 0.72
2002	76.5	10.58	-3.84	0.96
2003	74.0	15.46	+1.04	0.74, 0.73
2004	70.4	11.03	-3.39	0.61
2005	71.5	15.45	+1.03	0.54, 0.60, 0.51, 0.88, 0.88
2006	72.9	15.76	+1.34	0.72, 0.62, 0.80, 0.58
2007	75.2	14.96	+0.54	0.86, 0.55, 0.55, 0.56
2008	71.3	16.36	+1.94	0.65, 0.54, 0.54, 0.98
2009	70.1	13.68	-0.74	0.56, 0.64
2010	73.2	13.90	-0.52	0.71, 0.84
2011	71.8	17.48	+3.06	0.54, 1.78, 0.91, 0.57
2012	74.7	15.27 (est)	+0.85	0.54, 0.82

+Defined as average maximum temperatures for June, July and August.
++Maximum 24 hour precipitation amounts are listed as maximum daily rainfall exceeding 0.5 inches for each month, as an indication of larger storm events.

Plant cover response to organic amendment in field conditions

Plant transects were measured in Fall of 2007, 2008, 2009 and 2012 (Figures 18 and 19). The changes in plant cover measured during this period were non-significant (Table 4; p values > 0.10). Revegetation grass cover in 2009 dipped slightly. This year was slightly below normal in precipitation, but it followed two years of elevated precipitation. Abundant gopher activity was observed at different times, which may have been increased by abundant plant production followed by return to normal or below normal rainfall. But, even with these fluctuations, overall trends did not show increases of exposed rock or dirt. The grass cover on the Native soil was lower for 2012 and there were signs of tree felling disturbance activity in the area. Overall, though, cover was not significantly different across the four years measured. Photo pairs 3 and 4, 9 and 10, and 13 and 14 show the same areas in 2008 and 2012.

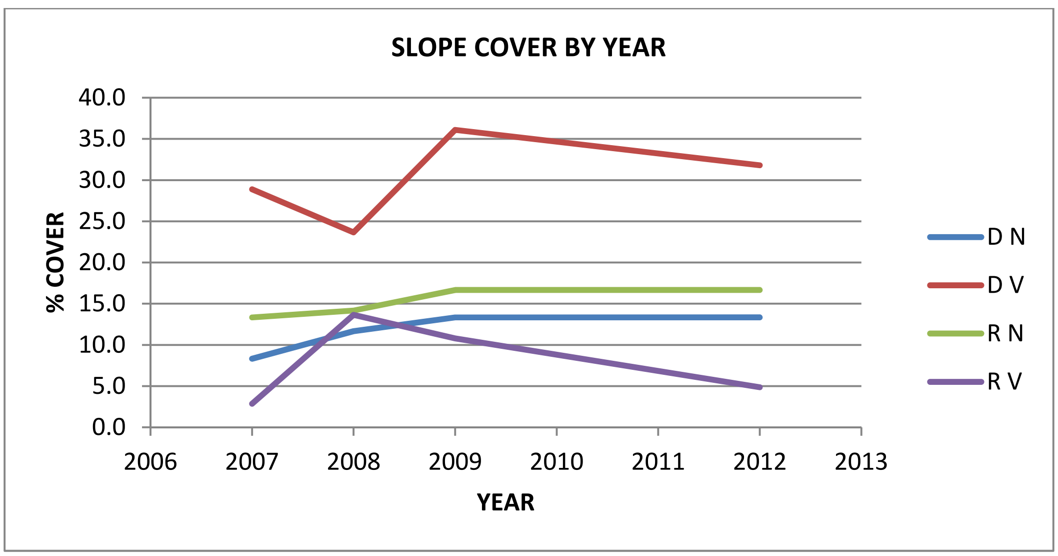

Figure 18. Percent cover of dirt or soil (D) and rock (R) on Native soil (N) or Revegetated plots (V).

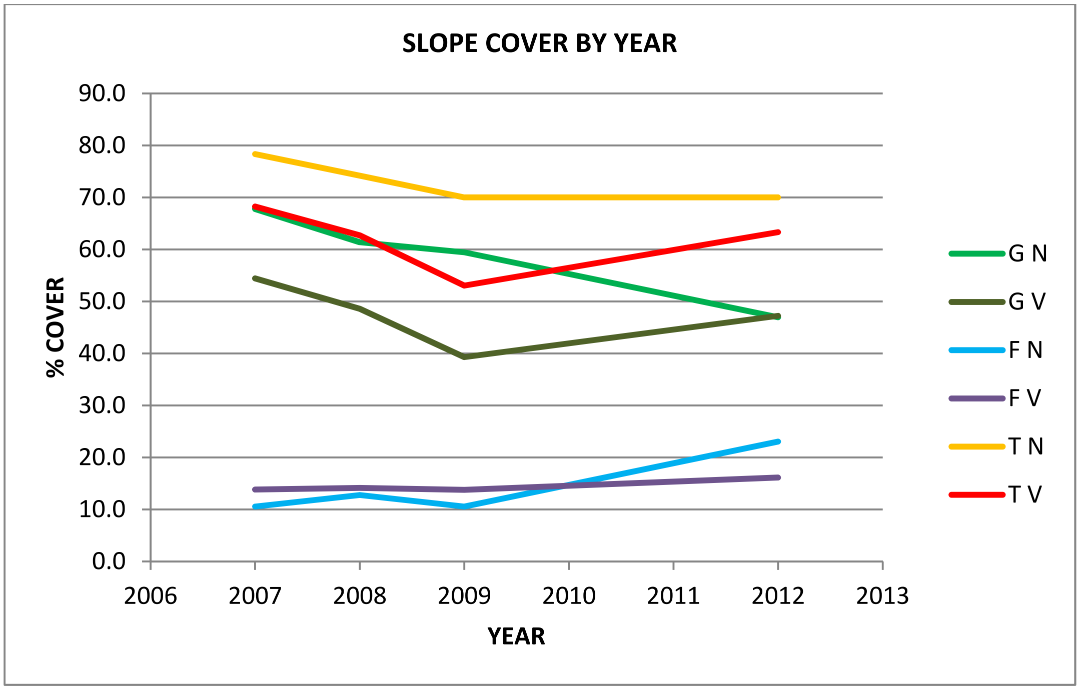

Figure 19. Percent cover of grass (G), forbs (F) or total cover (T) on Native soil (N) or Revegetated plots (V).

Table 4. Plant cover percentages for different years and statistical significance across years.

			% Total Cover			
	N	**V**	**N**	**V**		
Year	**Dt**	**Dt**	**Rk**	**Rk**		
2007	8.3	28.9	13.3	2.9		
2008	11.7	23.7	14.2	13.7		
2009	13.3	36.1	16.7	10.8		
2012	13.3	31.8	16.7	4.9		
	N	**V**	**N**	**V**	**N**	**V**
	Gr	**Gr**	**Fb**	**Fb**	**TotPl**	**TotPl**
2007	67.8	54.4	10.6	13.8	78.3	68.3
2008	61.4	48.6	12.8	14.1	74.2	62.7
2009	59.4	39.3	10.6	13.8	70.0	53.1
2012	46.9	47.2	23.1	16.1	70.0	63.3
p =	0.12	0.67	0.45	0.97	0.37	0.43
N = Native (n = 4); V = Revegetation (n = 7 or 8);						
Dt = dirt; Rk = rock; Gr = grass; Fb = forb, TotPl = total plant cover						

Soil nutrient testing

The preliminary finding from soil testing is that these soils and substrates are not substantially constrained by toxicity or nutrient level, other than nitrogen (N) or moisture availability. Some nutrient elements are low relative to agricultural standards, but lower biomass production on these wildlands sites means the nutrient levels may not constrain plant growth. Data and general target values are included in Table 5. As site growth conditions become more harsh, however, marginal availability of some nutrients can sometimes generate negative effects. In contrast to the ability of many soil nutrients to constrain growth, increases in plant available moisture and N commonly cause plant growth to increase. A practical strategy is to treat the substrate to provide the desired growth by regenerating moisture and N availability while merely preventing reductions in growth by deficiencies in all other nutrients. The general acceptable levels of nutrients are listed within each column as approximate 'target levels' for reference.

Table 5. Soil nutrient data using conventional agricultural tests with interpretation for wildlands growth conditions.

Straight Creek cut slopes, CO I-70						A&L report number 08-154-005					samples	53852	to	53905			
Veg	plot	pit	depth	OM	P1	HCO3_P	PH	BUFFER_PH	K	MG	CA	NA	CEC	K_PCT	MG_PCT	CA_PCT	NA_PCT
				%	ppm	ppm			ppm	ppm	ppm	ppm	cmol/kg	%	%	%	%
Nat	all		top	4.5	26.0	25.2	5.7	6.8	214.7	186.3	906.4	34.8	8.6	6.3	18.3	51.4	1.8
Nat	all		sub	2.9	29.6	26.3	5.6	6.8	130.7	133.6	807.8	33.6	7.4	4.9	15.5	52.0	2.2
Nat	all		deep	2.1	19.5	23.7	5.5	6.9	98.3	98.2	503.8	29.1	4.9	5.7	15.9	49.7	2.9
Nat	all		bare	1.3	15.6	15.5	5.9	6.7	81.7	244.8	1792.0	163.9	14.6	1.5	13.9	61.1	4.8
Hi	5		surf	1.3	18.5	11.8	6.8		97.5	185.2	885.0	231.1	7.5	3.3	20.2	59.5	13.4
Hi	6		surf	1.2	15.6	13.0	6.2	6.9	173.5	277.0	1070.1	79.2	9.6	5.0	24.1	55.0	3.8
Hi	7		surf	1.0	24.2	14.9	6.2	7.0	105.3	168.0	357.4	49.8	4.2	6.4	33.8	42.8	5.1
Lo	1		surf	1.0	20.4	14.0	6.1	6.9	101.6	86.2	706.8	34.5	5.4	4.8	13.2	65.9	2.8
Lo	2		surf	1.3	17.4	14.5	5.6	6.8	111.6	87.8	766.3	39.1	6.6	4.4	11.0	58.4	2.7
Lo	3		surf	0.9	5.0	6.3	6.3	6.9	148.5	199.5	1372.3	78.4	10.2	3.9	16.2	66.2	3.7
Lo	4		surf	1.5	13.5	12.7	6.1	6.8	145.9	251.6	1662.0	50.0	12.8	2.9	16.3	64.7	1.8
Lo	bare		surf	1.0	23.2	17.4	6.1	6.9	116.5	230.3	852.0	84.5	7.9	4.0	24.55	51.95	5.05
target levels				1.5 - 2.0	> 10	> 5	> 6	x	> 100	> 50	> 300	x	> 10	> 1.5	x	> 20	< 13
Veg	plot	pit	depth	NO3_N	S	ZN	MN	FE	CU	B	S__SALTS						
				ppm	ppm	ppm	ppm	ppm	ppm	ppm	dS/m						
Nat	all		top	2.6	6.6	2.1	39.8	75.0	0.9	0.3	0.3						
Nat	all		sub	1.2	4.4	0.9	33.0	55.6	1.0	0.3	0.2						
Nat	all		deep	0.9	10.8	0.3	9.0	44.2	0.7	0.2	0.2						
Nat	all		bare	6.5	12.8	0.6	16.1	21.0	0.8	0.2	0.9						
Hi	5		surf	1.6	4.7	1.1	6.3	18.9	1.1	0.3	0.2						
Hi	6		surf	1.4	3.6	1.4	9.5	18.2	1.0	0.3	0.2						
Hi	7		surf	2.1	4.9	1.0	7.5	15.6	0.8	0.2	0.3						
Lo	1		surf	1.5	2.8	0.4	4.2	16.7	0.6	0.2	0.2						
Lo	2		surf	1.3	2.7	0.3	5.3	29.5	0.5	0.2	0.2						
Lo	3		surf	3.1	3.4	1.4	11.4	19.1	2.2	0.2	0.2						
Lo	4		surf	1.3	3.3	0.8	12.0	24.7	2.2	0.3	0.3						
Lo	bare		surf	1.4	3.2	1	13.8	17.9	0.8	0.25	0.3						
target levels				x	x	> 1	> 10	> 10	> 1	> 1	< 2.0						

Extractable N versus N loading

The amount of ‘plant available’ N is estimated by conventional soil extraction tests commonly used in agricultural or forestry soil evaluation. The conventional understanding is that a short term extraction can be interpreted and used to estimate the amount of inorganic N (ammonium and nitrate) available to the plant on a relatively short term basis, such as days to weeks. If soil organic matter pools are large and can continually recharge the short term extractable pools, the steady supply of plant available N can continue. But in degraded sites there typically is no reserve pool of soil organic matter or repeated fertilization as in agricultural systems. In these cases, extractable N only indicates a few days to a week or so of N availability, after which it is depleted. Additional extractable pool N may come in from seepage from well vegetated areas up-slope or from atmospheric deposition from the nearby traffic, but these sources may be small and or erratic. They were not evaluated as part of this study.

The ammonium and nitrate release rates from the three soil amendment treatments are shown in Figures 20, 21 and 22. There was some residual ammonium in the zero control (unamended DG substrate), but this amount has already been subtracted from all graphs for extractable N values; the values presented can be interpreted as all coming from the amendment. Similar to the nutrient release tests done in the lab previously (Appendix A), the soil amendments gave a strong N release over the first few sampling events. This spike was mainly made up of ammonium in these samples, whereas in the lab incubation that had controlled extraction volumes and no leaching losses the main N product was nitrate. This is assumed to result because of frequent leaching events in the field that resulted in the very soluble nitrate being removed from the amended horizons.

The G treatment was the most completely extracted by the initial leaching. Approximately 83 % of the full amount released within the entire four year incubation period was released in an available form during the first extraction, which is equivalent to the first wet-up or saturating rain event in the field. When the samples were collected after the first winter season in S09, nearly 89 % of the total amount released had been in an available form. This suggests that N in the G amendment will be nearly completely released in the first few rain or snow melt events after installation before plants germinate and start growing in the spring. During this season of high water flow during melt off, much of this available N is probably removed from the rooting depth. Subsequent extractions through the rest of the study (F09 to W12) indicate a release of an additional 11 % of available N.

The B and H treatments also have a predominance of early N availability, but for these amendments only about 6 to 7 % of the total release occurs during wet-up (the initial extraction). During the first spring / early summer growing season, about 70 % of the full extractable N release occurs, which is during the first period of rapid plant growth and uptake. Through the rest of the study (F09 to W12) another 25 % of available N is released. Ammonium is the primary N form retained in the amended soils and extracted during analysis.

The addition of humus materials in the H treatment shows a somewhat reduced peak (S09) and slightly increased tail (F09, S10) compared to the B treatment. Since these are the same N

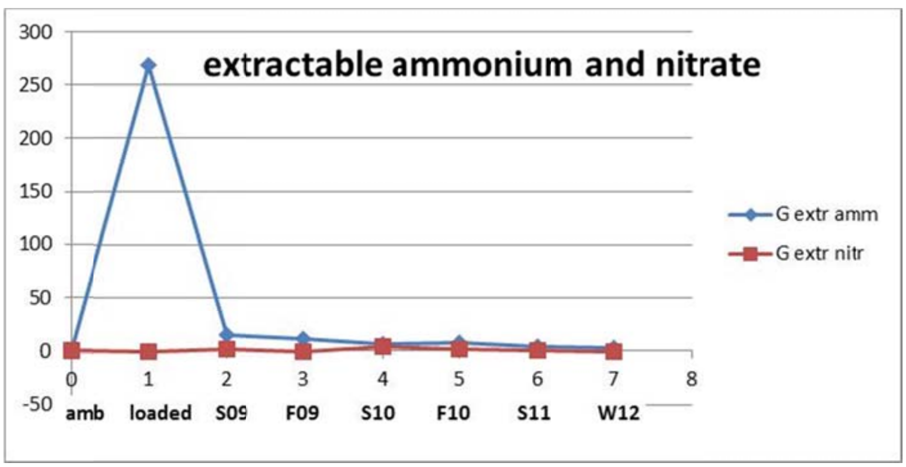

Figure 20. Extractable (inorganic) nitrogen in mg N/kg soil for soil amendment G. Note that the large amount of N released by this amendment required an approximately three times larger Y axis scale.

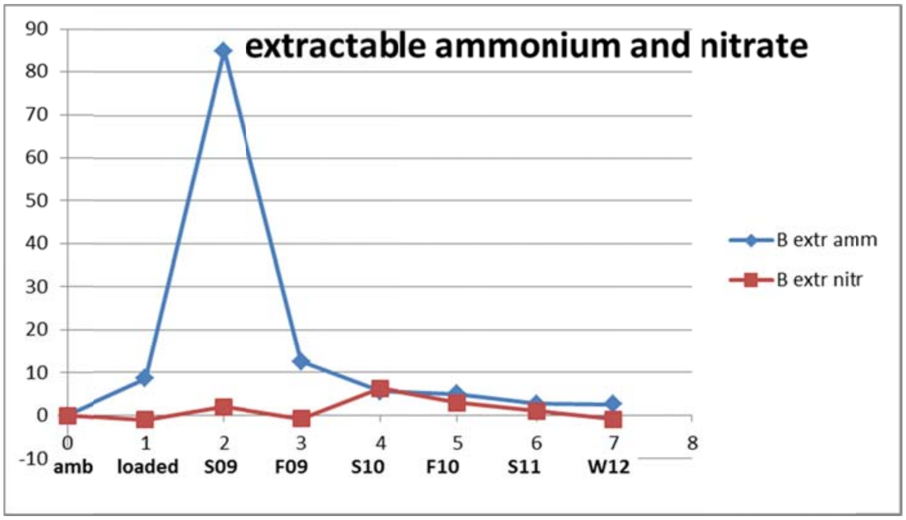

Figure 21. Extractable (inorganic) nitrogen in mg N/kg soil for soil amendment B.

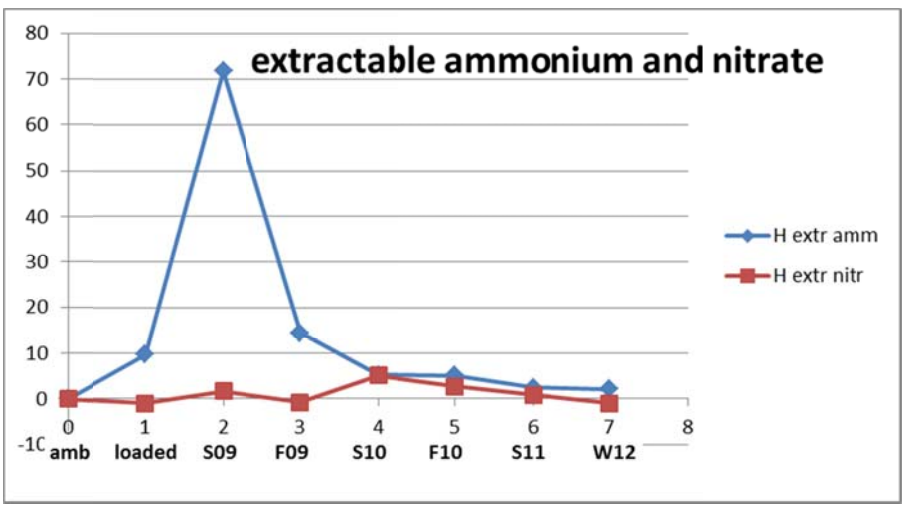

Figure 22. Extractable (inorganic) nitrogen in mg N/kg soil for soil amendment H.

amendment with the addition of the humus material, this indicates a small but detectable effect on extractable N amounts. There may be other benefits for plant growth on degraded soils but they were not evaluated in this study.

When the B and H treatments were compared for cumulative extractable N delivered to the soil (Figure 23), they showed the same general curve shape as measured in fully controlled lab conditions with full capture of all leached N. This suggests the incubation columns under field conditions performed similarly to the controlled lab columns. About 70% of the extractable N released during the study period was released in the first season of the first summer growth period. Then the remaining approximately 25 % was gradually released over the next approximately three years. The mechanism of N release in these materials is expected to be biologically driven. Cooler winter temperatures appear to cause a general reduction of N mineralization and release.

The actual field availability of ‘available N’ in the plant-soil revegetation system in the field depends on the ability of plants to capture this initial pulse of N. This plant tissue can sequester amendment N the first season and then decompose and re-release that same N in subsequent seasons. But in these experiment conditions, plants were excluded in order to more specifically evaluate the N release from the amendment itself. Only a few roots penetrated the bottoms of the incubation columns and then only after the second year.

When the cumulative extractable N release of the B and H treatments were compared to the N release from the G treatment, the more rapid release pattern of the G material can be readily seen (Figure 24). This material releases about 85 % of its total extractable N release and this comes out during the first lab extraction of the first samples measured, without any field leaching. In contrast, the B and H treatments release approximately 6 to 7 % of their N during the initial wet-up, showing low water-soluble forms of N in these materials.

Because the same total amount of N was loaded into the amended horizons for all three treatments, this figure also suggests that although the B and H treatments appear to reach their maximum extractable N delivery for the project period, there is still another large portion of N remaining in the residual soil organics that has not been mineralized or decomposed and released to the extractable N pool. This N may have other functions in the soil such as promoting soil organic matter accumulation. But it does not appear to be immediately available for plant growth.

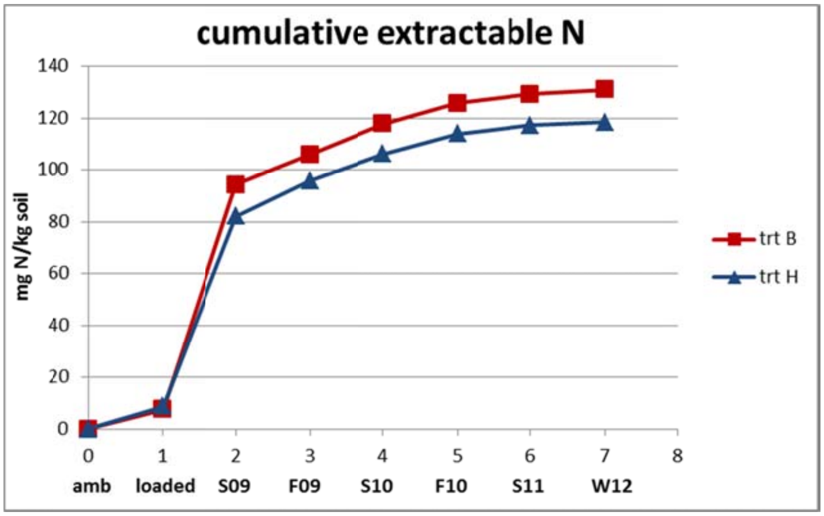

Figure 23. Cumulative extractable (inorganic) nitrogen in mg N/kg soil for soil amendments B and H. Note difference in Y axis values between Figure 23 and 24.

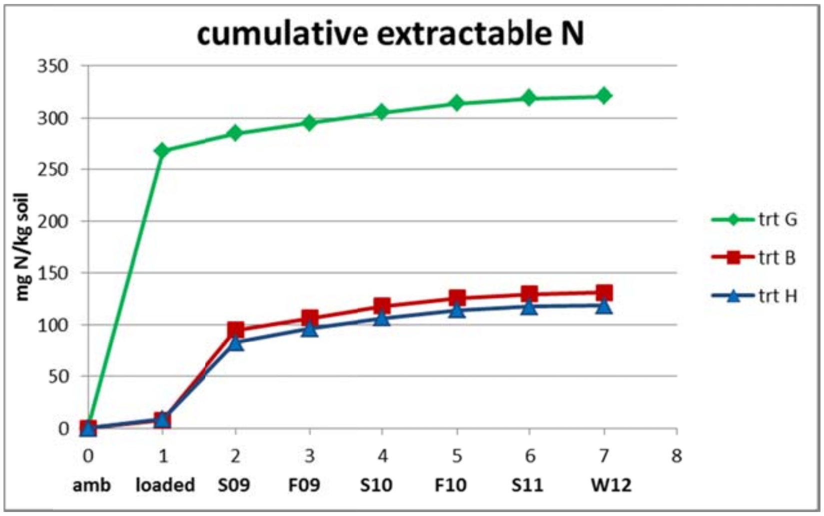

Figure 24. Cumulative extractable (inorganic) nitrogen in mg N/kg soil for all soil amendments. This figure plots the higher N release from amendment G on the same curves from Figure 7.

Leaching versus loading

An additional test of the ability of the experimental setup to track extractable N pools during nutrient release is shown in Fig 25. These data show the extractable N that was stored in the next soil horizon beneath the amended horizon in the field incubation tubes. The first information is that the Y axis showing mg N/kg soil is all 10 mg N/kg or lower. Compared to the previous graphs (Figures 20 - 22) this is a small value. This suggests that little N is retained in the subsurface horizons; it is either retained in stabilized N forms or leached through the profile in the field. The subsequent year, most is subsequently removed in the following winter season, when the curves go to less than one for B and H and about 4 mg N/kg for G.

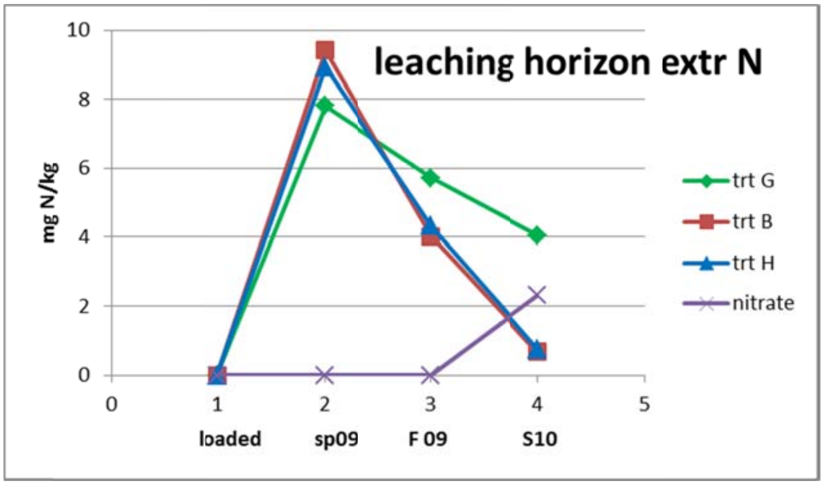

Figure 26. Extractable (inorganic) nitrogen in mg N/kg soil recovered from leaching horizon. Note the small levels of N and low values on the Y axis.

Total N and total C

The amount of *total* N analyzed in a sample is a sum of all chemical forms of N in the soil. This includes the extractable inorganic N forms (ammonium and nitrate), the decomposable organic forms of N and the chemically stable N in the humus sample as well as fixed N in the mineral interlayers. Total N, along with the Total C content are obtained from a sample by burning at high temperature and evaluating the actual C and N gasses that come off of the sample. So, while the extractable N is a small subset of the amended material, the total analyses will include the soil's whole N and C content. This large and heterogeneous pool is relatively easy to measure, but has lower resolution than the extractable N analyses.

The % Total N graphic (Figure 27) shows that the initial loading of the three amendment materials was fairly close but not exact. The published values for these amendments were used in loading the incubation columns by weight. The requirement for reported fertilizer analysis is to guarantee a minimum content, so some of these materials may have had more than the indicated amount. Plus, the 1 % N content listed for the H treatment was in an unknown humus chemical form and was not included in the loading rates. None-the-less, the total N contents indicate that the different treatments were loaded to similar levels.

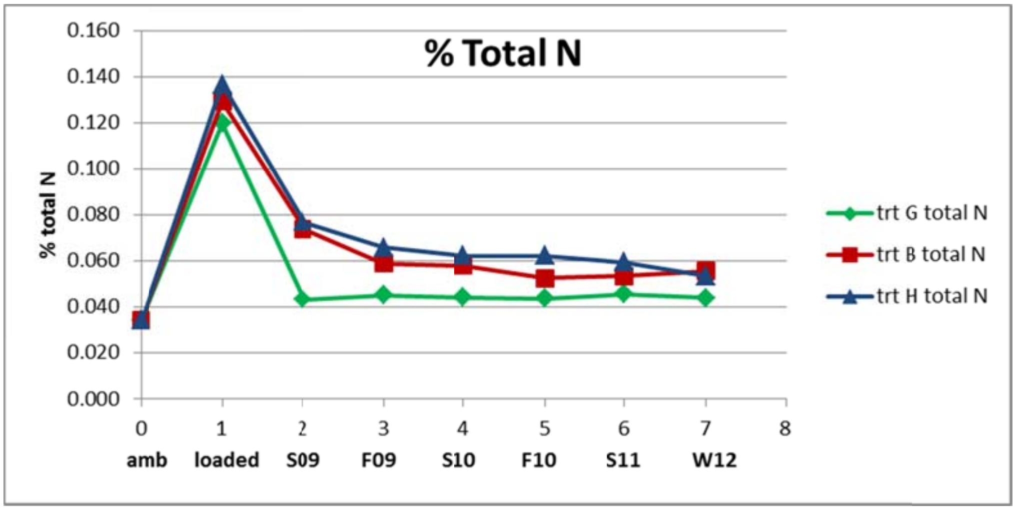

Figure 27. Measured % total N for all soil amendment treatments.

From the second time period onward (S09 and later) the quick release of available N from the G amendment is shown by a rapid decrease in the total N content. The B and H materials retained a greater proportion of their organic N, which would be mineralized into extractable inorganic N forms later. The general trend of the H samples was to retain slightly more N in the soil than the B samples although the reason for this is not clear either for chemistry or statistical significance.

On the basis of measured total N levels of organic residues in the B and H amendments, 58 % of the amendment total N applied appears to be released in the early in the first growing season (spring, early summer). By the end of the first summer, another 16 % had been released from the total N pool in the columns. Another approximately 7 % is released in years three and four after application. Approximately 19 % of the applied total N in the amendment remains as a persistent organic residue after three years. The stability and release rate of this stable pool are of interest for the soil building processes shown in Figure 31 at the end of this section, but were not measured as part of this study.

The Total C content (Figure 28) more strongly showed the addition of the high carbon humic material to the amended soil in the H treatment. Only a limited amount of this C was lost during decomposition compared to the B and G treatments. The retention of high levels of carbon in the

G treatment after F09 suggests a resistant form of C in this material also. The label describes '70 % humus' and '15 % humus acids,' although these terms are not well defined and will all have different decomposition rates.

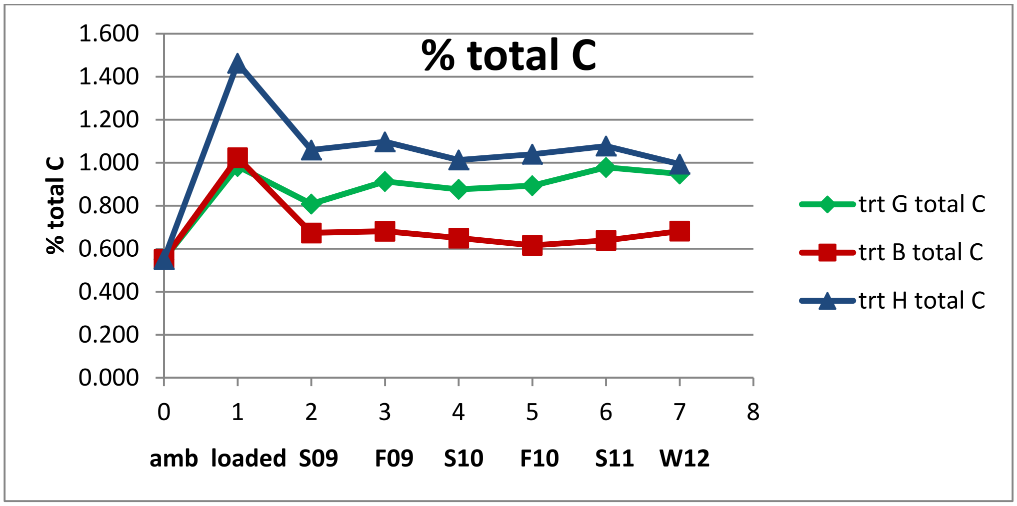

Figure 28. Measured % total C for all soil amendment treatments.

In general soil science, the proportion of total C and N, i.e. the 'C:N ratio,' is often used to indicate how stabilized a soil organic matter content is. This is generally based on the observation that cellulose-rich plant stalks or wood with a low % N content tends to decompose and sequesters any available N to build the population of microbial decomposers. So, the material "immobilizes" N into microbial biomass and plants growing on these materials have a hard time getting sufficient N and tend to be N deficient. Conversely, very well decomposed materials have much less carbon left, so when microbes decompose it they tend to have surplus N and release it into extractable forms as 'mineralized,' or 'plant available' N. The general guideline is that C:N ratios over 20 or 25 immobilize N while those with C:N ratios less than 20 tend to mineralize, or release N. These are generalizations that depend on particle size and chemical characteristics. Stabilized soil organic matter tends to have a C:N ratio of around 10, so the slow decomposition of this material yields a steady release of N. Soil amendments are much less stable than SOM, so faster decomposition occurs and N release varies widely.

The C:N ratios for the three amendment materials (Figure 29) indicate that when first wetted ('loaded', or extraction #1) the carbon is more rapidly decomposed than N, so the C:N ratio of all amendment materials initially decreases. But then as the seasons progress, the C:N ratio increases. This indicates that N is being utilized (immobilized) and remaining C is harder to decompose. As the C accumulates, the C:N ratio increases. This may occur because the remaining carbon is the recalcitrant humus materials that remain in the G and H treatments. In contrast, the B material (same as H but without the humus) retains a lower C:N ratio suggesting a continued tendency to release N as the carbon fraction decomposes. Additional analysis of organic residues would be needed to understand these outcomes. Humic materials do not contribute to the release of mineralized N although they have other benefits to soils and soil function. The G material has the highest C:N ratio, topping out around 22. This may be attributable to rapid loss of soluble (highly available) N early in the field experiment, leaving a higher carbon residue behind and not enough N to build the microbial biomass needed to decompose it. Alternatively, the high C:N ratio could result from the supplemental humic acid addition. When two very different organic materials are mixed, they sometimes do not interact extensively, and instead, behave as two separate amendments in the field. Chemical analysis of these residues would help explain the cause of these different curves.

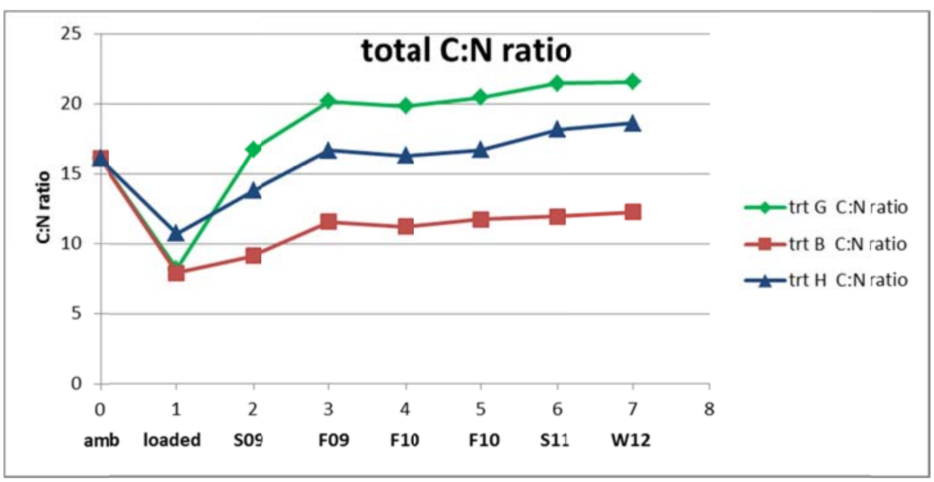

Figure 29. Measured C:N ratio for all soil amendment treatments.

Soil analysis provides many clues to evaluate and understand soil function. Beyond these data points, though, the emergent properties of sustainable revegetation, nutrient cycling processes and erosion resistance can best be seen in graphic example in a functioning soil. Figure 30 shows a grass and forb stand (plot V3, Figure 11) on what was previously bare decomposed granite, as in Figure 1. It is now a resaonably stable, functioning plant-soil system. A closer examination of the rooting volume under this forb (coarse roots) and grass (fine roots) system indicates a vibrant soil that is actively forming individual particles into aggregates that increase infiltration and nutrient retention. Increased infiltration reduces overland flow for erosion resistance and retains more organic duff to build the soil. The processes are already well started on these slopes with no direct signs of vegetation thinning. Continued occasional amendment when thin is expected to continue this beneficial trend. The timing of these is unknown but may be a decade or more. A specific test for the biologically active versus stabilized organic matter on these disturbed slopes would enable closer monitoring of these regenerating sites.

Figure 30. An example soil pit on a lower revegetation cover plot showing extensive root development into the previously non-living decomposed granite substrate.

Figure 31. Close-up photo of same rooting profile showing extensive fine root distribution throughout the upper part of the substrate and granular-shaped, organically bound soil aggregates adhering to the fine roots.

CONCLUSIONS AND RECOMMENDATIONS

This study evaluated three questions about revegetation on these degraded slopes:

1) Is vegetative cover stable?

No decreases in overall vegetation cover were measured during this study period.

2) Is there baseline soil fertility?

Adequate soil fertility exists in the substrates except for long-term supplies of N and possibly stabilized organic matter pools. Soil moisture will always be scarce on these sandy materials, so reducing crusting and increasing infiltration are critical for stormwater capture.

3) What are the release rates of typical CDOT soil amendments?

The measured soil amendments released N primarily in the first growing season but slower release occurred for three more years.

While no reapplication is needed in the near term, any combination of environmental factors that causes thinning of the canopy (severe weather, increased herbivory, or just gradual loss of nutrients) should be quickly addressed with a smaller, supplemental reapplication to maintain good soil function and vegetative cover. The system should not be allowed to decline with the thought of re-amending at a later time. Given the high erosion potential of these slopes, maintenance amendments are recommended over regeneration amendments. Smaller amendment rates, perhaps 500 to 800 lb/ac may be able to be blown on rapidly with a light application of wood chips or wood fiber as a carrier. This would thicken up the stand without encouraging weed invasion.

What was not measured in this study is the size and stability of the soil organic matter pools that are observed to be regenerating as shown in Fig 31. How long-lasting or stable are these new soil organic matter pools are and how often would they need to be regenerated with additional amendment is not known. Tests that detect this type of soil organic matter pool could also be used to evaluate whether other blends of organics could recreate this same level of plant-soil vigor, perhaps in only a few years after construction rather than requiring several reapplications and several decades of time to reach this stage.

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APPENDIX A

Reference graphs for N release from previous studies.

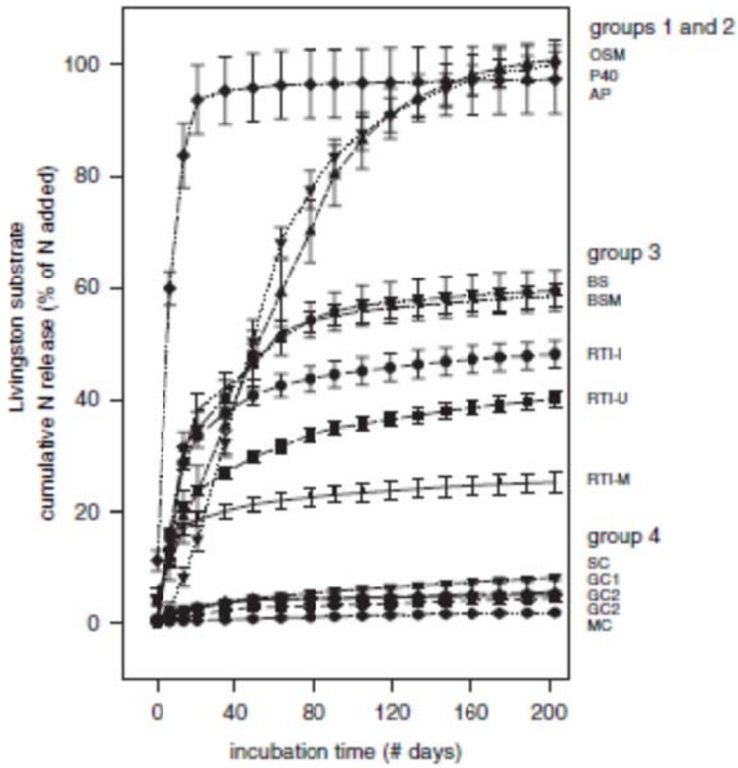
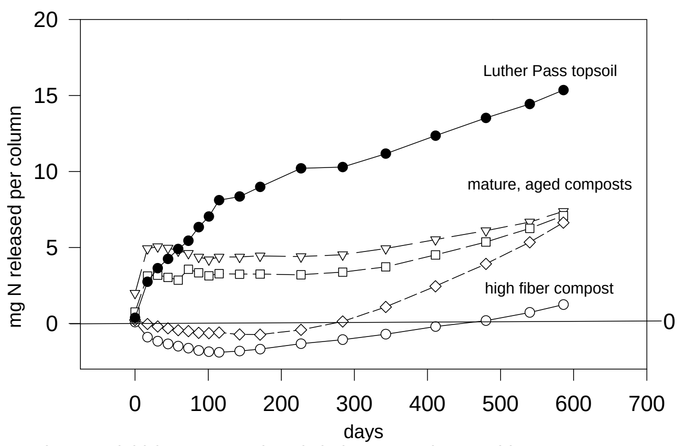


Figure 1. Cumulative N release by extraction from soil amendment materials on Livingston substrates (percentage of N added) during laboratory incubation at 30°C. Group 1 amendments are chemical formulations; group 2 are slow release chemical formulations; group 3 are organic based blended materials and group 4 are unblended municipal yard waste composts. All data points have standard error bars, some of which may be hidden by the plot symbol.

Claassen, V.P., J.L. Carey. 2007. Comparison of nitrogen release rates from slow-release fertilizers and organic soil amendments. Land Degradation and Development. 18 (2): 119-132 MAR-APR 2007



Nitrogen yield (mg N per column) during a 586 day aerobic incubation of topsoil from Luther Pass in the Tahoe Basin and decomposed granite sands receiving amendments (500 kg N/ha) of various composts.

Claassen, V.P. and J.L. Carey. 2004. Regeneration of Nitrogen Fertility in Disturbed Soils Using Composts. Compost Science and Utilization 12(2):145-152.