EFFECTIVENESS OF SOIL AMENDMENTS AND REVEGETATION TREATMENTS AT HUCKLEBERRY MINE, HOUSTON, BRITISH COLUMBIA

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ABSTRACT

Supplies of topsoil are often limited for use in mine reclamation activities; it may be necessary to build soils using locally available substrates. Revegetation test plots were established at Huckleberry Mine, Houston, B.C., to investigate the performance of seven native plant species treatments on stockpiled topsoils amended with (or without) non-acid generating (NAG) sand (obtained from desulphurized copper tailings) and NPK fertilizer. Seeding treatments (single or mixed species) consisted of species native to the mine site (local genotype) obtained from commercial seed (mixed genotype). Soil sampling and vegetation monitoring were conducted during for two growing seasons. NAG sand reduced some soil properties conducive to plant growth (e.g. cation exchange capacity), yet plant performance was not significantly lower than in soil-only plots. When combined with a fertilizer, plant performance significantly increased over non-amended topsoils. Trace element concentrations in supplemented soils were low and should not adversely affect plants or the local environment. Plant performance of blue wildrye (mixed genotype variety) was shown to be higher than all other species examined and is suggested as the best candidate for the revegetation at Huckleberry Mine.

Key Words: reclamation; stockpiled topsoil; amendments; native plant species; desulphurized tailings; fertilizer

INTRODUCTION

A soil amendment can be defined as a material that is applied to a substrate in an effort to improve the essential conditions required for adequate plant growth, and/or for reducing the mobility and bioavailability of any soil contaminants. Amendments are often used in the reclamation of soils and unconsolidated overburden, which in almost all cases, lack optimal conditions for plant growth. These substrates can generally be described as having potentially low levels of plant-available nutrients (e.g., nitrogen [N] and phosphorus [P]), high concentrations of heavy metals, low organic matter content, high salt content and lower or higher than normal pH (EPA, 2006).

Depending on the type of mine operation and the mineral resources being extracted, a variety of substrates are created as a result of ground disturbance and the production of waste materials from excavated surface and parent material substrates, as well as from the processing of mineral concentrated materials. Overall, there are three major substrates that are commonly produced on mined lands: (i) disturbed and degraded topsoil and unconsolidated overburden, (ii) waste rock materials and (ii) processed mine tailings.

Disturbed and degraded topsoils and unconsolidated overburden are produced when the materials are removed and transported to storage locations during site clearing for mine operations. A considerable amount of topsoil can be lost as a result of handling and transport. For topsoil that is successfully salvaged, soil quality -- defined as the ability of a soil to perform the functions and provide the elements essential for plant and animal growth (Brady and Weil, 2002) -- is often greatly reduced as a result of compaction from heavy machinery, disruption of soil structure and the deterioration of soil biota in long-term storage.

Desulphurized tailings may be produced during the milling process, in which the sulphidic fraction of the slurry is removed through an additional flotation stage, resulting in a relatively pH-neutral material (Benzaazoua et al., 2000). In the early 1990's, treated tailings (known as desulphurized or depyritized tailings) were introduced as a cover material for tailings impoundments (Sjoberg et al., 2001). During the last few years of mine life, treated tailings are produced and then used to cap the sulphuric portion of the tailings impoundment with a layer 1 to 2 m in depth; this layer reduces the oxidation of underlying sulphide minerals by limiting oxygen and water availability (Sjoberg et al., 2003).

At Huckleberry Mine, an open-pit copper/molybdenum mine located approximately 86 km southwest of Houston in west-central British Columbia, substrates available for reclamation include stockpiled topsoil, desulphurized NAG (non-acid generating) sand (utilized as a cover material for the tailings management facility [TMF]-2), peat, and glacial till. Due to inadequate salvage and storage practices in the past, the supply of topsoil at Huckleberry Mine is limited. As an alternative to locating additional sources of topsoil, this experiment sought to determine whether the addition of NAG sand could act as a volume-enhancing amendment to stockpiled topsoil, increasing the amount of suitable growth medium available for use in reclamation. It was hypothesized that by mixing NAG sand and topsoil, the amount of suitable growth medium available for reclamation could be increased with no detrimental effects on vegetation establishment and performance.

To evaluate the suitability of NAG sand amended topsoil as a medium for plant growth and to identify candidate species for revegetation of stockpiled topsoils at Huckleberry Mine, the performance of six native species (three grasses, one sedge and one legume) sown in NAG sand amended and non-amended 2- and 10-year old stockpiled topsoils was observed. Seed stocks for each species were either collected from the local area of the minesite (local genotype) or from genetically diverse (mixed genotype) seed stocks. In addition, the performance of blue wildrye established from locally collected and genetically diverse seed stocks was compared to evaluate the effects of seed origin on plant establishment and productivity and to assess whether the higher costs of obtaining local seed stocks were justified. Furthermore, physical and chemical properties (including trace elements and base metal concentrations) of

NAG sand amended and non-amended topsoils were compared to assess whether the addition of NAG sand would result in adverse effects to plant growth and the environment.

METHODS

Seed Collection

In August and September, 2008, seeds of blue wildrye (*Elymus glaucus*), arctic lupine (*Lupinus arcticus*) and Merten's sedge (*Carex mertensii*) were collected from the local area (within a 10-km radius of the minesite) at dates appropriate to their expected time of ripening. Seeds for arctic lupine were collected in the first week of August and seed for blue wildrye and Merten's sedge were collected in early September.

Following field collection, pod stocks of arctic lupine were stored in large paper bags (sealed closed) for approximately two weeks to allow pods to ripen and dehisce. Seeds from dehisced pods were then collected from the bottoms of each bag. Remaining unopened pods were crushed by hand and then crushed material was filtered through a 4 mm mesh screen and retained by a 1 mm mesh screen in order to extract and clean the seeds. Seed material collected from blue wildrye was similarly cleaned using soil screening equipment available in the metallurgical laboratory at Huckleberry Mine. For Merten's sedge, the attempt to purify seed stock through a series of sieves proved unsuccessful, as floral bracts were very similar to the seeds in size and shape. Therefore, seeds (with bracts) were separated from the inflorescence by hand and a seed purity analysis was conducted in order to estimate the number (proportion) of seeds within the total seed stock material.

Test Plot Construction

A total of twelve revegetation test plots were constructed at four different locations (three test plots per location) at the Huckleberry Mine minesite between September 22nd and October 6th, 2008. At each of the four locations, two topsoil amendment test plots were constructed using soil from either a 2-year topsoil stockpile or a 10-year old topsoil stockpile. Test plots at two locations were constructed using 10-year old stockpiled topsoil and the remaining two locations were constructed using 2-year old stockpiled topsoil. In addition, a single NAG sand test plot was constructed at each of the four test plot locations.

Topsoil amendment test plots measuring 10.4 m by 5.2 m were divided into thirty two 1 m^2 subplots, arranged in a split-strip-plot design (Little and Hills, 1978), and NAG sand test plots were divided into eight subplots (Figure 1). The topsoil amendment test plots were divided into two equal sections, each consisting of 16 subplots. In one section, the subplots were composed of a stockpiled soil and the other section, a 50:50 mix (by volume) of stockpiled soil and NAG sand. Within each of these treatment substrates, eight subplots were each fertilized with 576.9 kg ha^{-1} of 13-16-10 nitrogen, phosphorus and potassium (NPK) fertilizer; the remaining eight subplots were left unfertilized.

Each subplot was established on a 2.6 m^2 ground surface area with a substrate depth of approximately 20-25 cm, resulting in a subplot surface area of 1.0 m^2 and a 0.3 m buffer around the subplot perimeters. Following the completion of subplot construction, buffer spaces were backfilled using neutral parent soil from the area surrounding the test plots.

Test Plot Seeding

In total, seven seeding treatments were applied to all 12 test plots initiated on the minesite October 5th and 6th, 2008 (Figure 1). Treatments consisted of sowing either a single plant species or a mix of species. Seeds stocks included: i) native seeds collected from the local area of the mine (blue wildrye, arctic lupine and Merten's sedge; local genotype) and ii) seeds obtained from seed increase plots where seeds from a variety of locations were sown to generate genetically diverse seed crops (blue wildrye, fringed brome [*Bromus ciliatus*] and Rocky Mountain fescue [*Festuca saximontana*]; mixed genotype), also known as ecovars, by Industrial Forest Service Ltd. (IFS), located near Prince George, B.C.

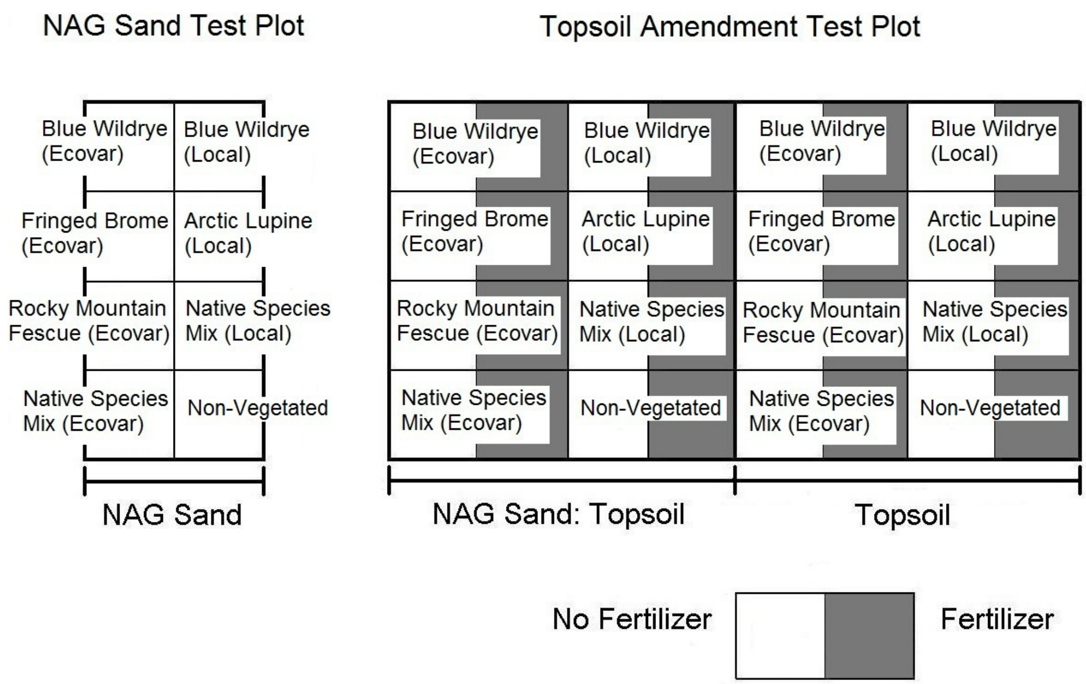

Figure 1. Overview diagram of substrate and seeding treatments (each square representing a subplot) for NAG test plots (left) and topsoil amendment test plots (right). Subplots were either seeded with one of the seven seeding treatments or designated as non-vegetated.

Treatments were applied to all subplots at a standardized sowing density of 750 PLS (Pure Live Seed) m^{-2} which was chosen based on optimal sowing densities recommended as the result of a previous study (Burton et al., 2006). Test plots were hand sown during the period of October 5-6th, 2008. Immediately after sowing each subplot, the soil surface was lightly raked to promote good seed/soil contact and to prevent seed loss from wind.

Test Plot Monitoring

Year 1 (2009)

Non-destructive sampling of vegetation was conducted in the twelve established revegetation test plots during late June and again in August of 2009. In subplots sown with a single-species seeding treatment, sampling included a count of seedlings and estimates of percent cover by species in both June and August, and plant height in August (no seedling counts were completed for Rocky Mountain fescue due to the difficulty in distinguishing individual seedlings from individual culms). For subplots sown with mixed-species seeding treatments, cover was evaluated and measurements of height were taken for each species.

Soil samples representing each of the treatment substrates were collected from the subplots within the 12 revegetation test plots in August 2009. The sampling design was chosen in an effort to obtain a sample of each treatment substrate that was representative across all subplots. For each substrate treatment, eight composite soil samples were collected. Each sample was collected from a group of subplots representing a specific substrate treatment. Within each subplot, three cores were collected using a regular 7.6 cm diameter soil auger to the depth of approximately 15 cm. All cores collected for each composite sample were collected into a 20 L bucket and mixed prior to packaging. Initial sample preparation was completed at the University of Northern British Columbia (UNBC) and the dried and sieved samples were then sent to the Ministry of Forests and Range Research Branch (BCMOF) Laboratory in Victoria, BC, and to ALS Canada Ltd., Vancouver, BC, for analysis.

Year 2 (2010)

In late August, 2010, vegetation was sampled from the 12 revegetation test plots. Sampling consisted of both destructive and non-destructive measurements. Non-destructive sampling was first completed and included percent cover and plant height determinations; destructive sampling followed, and consisted of harvesting above- and belowground biomass.

Aboveground biomass (live shoot biomass above the soil surface) was harvested by clipping the stems at the soil surface. The stems were then placed upright in a 20 L bucket and the number of seedlings was determined by counting the number of stems; for grasses, care was taken to distinguish primary and secondary shoots and only primary shoots were counted. No seedling counts were completed for Rocky Mountain fescue due to difficulties distinguishing between individual seedlings. In addition, representative seedlings (shoot and root biomass) were harvested from each of the subplots.

Once harvesting was complete, aboveground biomass and seedling samples were packaged in cardboard boxes and shipped to UNBC; samples arrived within 10 days of collection. At UNBC, above- and belowground biomass were gently washed free of residual soil and then oven-dried for 48 h at 70 °C.

In August 2010, soil samples (0 to 15 cm depth) were collected from subplots sown with local blue wildrye, ecovar blue wildrye and arctic lupine single-species seeding treatments. A composite sample composed of three core samples was collected from each subplot containing one of the three seeding treatments.

Samples for bulk density measurements were collected for the top 5 cm of each subplot using a volume excavation method (15.24 cm diameter ring, board, hammer and trowel). In addition, the compressive strength (kg cm^{-1}) of the soil surface was measured during soil sampling in all subplots using a pocket penetrometer (Humboldt Mfg. Co., model H-4200; Schiller Park, Illinois, USA).

RESULTS AND DISCUSSION

Soil Characterization

Differences in the physical properties between NAG sand amended and non-amended 2- and 10-year old stockpiled topsoils were quite apparent (Table 1). The addition of NAG sand to the topsoils resulted in an increase in the sand content and a proportional reduction in the amount of clay, silt and organic matter. This was expected, as the 50:50 mixtures of loam topsoil and NAG sand would necessarily have an intermediate soil texture. Bulk density of the topsoils increased and soil porosity (not reported) decreased in response to the addition of NAG sand. The change in bulk density and soil porosity was also accompanied by an increase in soil strength. As an incidental observation, the surfaces of topsoils amended with NAG sand were visibly darker when compared to the non-amended topsoils, which may have influenced surface temperatures (Troeh and Thompson, 1993). Furthermore, visual assessments of the surface of non-amended topsoils suggest that there may have been some surface sealing (i.e., crusting), which was not observed on NAG sand amended topsoils.

The addition of NAG sand to 2- and 10-year old stockpiled topsoils resulted in considerable changes to their chemical properties (Table 1). Cation exchange capacity (CEC) was shown to decrease in stockpiled topsoils with the addition of NAG sand. This was expected, as the addition of NAG sand would dilute the topsoil, lowering the organic matter and clay concentrations, thereby reducing nutrient retention (Brady and Weil, 2002). As a result of the lower capacity for nutrient retention, total and available macro- and micronutrient concentrations in topsoils amended with NAG sand were lower in comparison with non-amended topsoils (with a few exceptions) and concentrations of some nutrients were considered deficient for plant growth. The pH of stockpiled topsoils increased with the addition of NAG sand, most notably in 10-year old topsoil. Electrical conductivity (EC) increased and calcium carbonate equivalence slightly decreased with the addition of NAG sand to stockpiled topsoils.

To provide context for trace element concentrations, values were compared to Canadian Council of the Ministers of the Environment (CCME) soil quality guidelines for agricultural soil (data not shown). Total concentrations of trace elements (including base metals) in NAG sand amended topsoils were found to fall within acceptable concentrations outlined in the Canadian Environmental Quality Guidelines (CEQG) for agricultural land, with the exception of chromium (Cr), molybdenum (Mo), vanadium (V) and copper (Cu; CCME, 2004). However, when comparing NAG sand amended soils to background levels found in non-amended topsoils, only V was found to be significantly higher in the amended topsoils. Vanadium is an element that has been shown to have low mobility and phytoavailability (Martin and Kaplan, 1998).

Table 1. Mean values (± SE) of physical and chemical soil properties in NAG sand amended and non-amended 2- and 10-year old stockpiled topsoil (n=12) and NAG sand (n=12).

	2-Year Topsoil		**10-Year Topsoil**		
	Topsoil	**Topsoil + NAG sand**	**Topsoil**	**Topsoil + NAG sand**	**NAG sand**
Physical Properties					
Coarse Fragments (%)	56.1 ± 6.3	32.4 ± 5.8	43.2 ± 4.3	22.3 ± 3.4	1.4 ± 0.3
Sand (% of fine fraction)	51.3 ± 0.3	80.5 ± 0.7	46.3 ± 0.4	77.7 ± 0.5	89.5 ± 0.3
Silt (% of fine fraction)	29.4 ± 0.4	12.6 ± 0.4	32.5 ± 0.3	13.5 ± 0.3	6.3 ± 0.5
Clay (% of fine fraction	19.3 ± 0.4	6.8 ± 0.3	21.2 ± 0.3	9.1 ± 0.4	4.2 ± 0.3
Bulk Density (g cm^{-3})	0.76 ± 0.12	1.17 ± 0.09	0.80 ± 0.04	1.18 ± 0.02	1.23 ± 0.02
Soil Strength (MPa)	0.031 ± 0.003	0.14 ± 0.002	0.069 ± 0.005	0.23 ± 0.003	0.011 ± 0.004
Soil Organic Matter (%)[b]	2.75 ± 0.16	1.09 ± 0.28	3.13 ± 0.16	0.58 ±0.32	<0.01
Chemical Properties					
pH (water)	7.08 ± 0.10	7.31 ± 0.04	5.61 ± 0.03	7.16 ± 0.03	8.25 ± 0.03
Total Carbon (%)	1.25 ± 0.08	0.45 ± 0.03	1.51 ± 0.05	0.36 ± 0.02	0.09 ± 0.02
Total Nitrogen (%)	0.06 ± <0.01	0.07 ± 0.003	0.09 ± <0.01	0.02 ± 0.001	<0.01
Total Sulphur (%)	0.42 ± 0.02	0.23 ± 0.01	0.04 ± <0.01	0.16 ± 0.003	0.19 ± 0.01
Total Organic Carbon (%)[a]	1.10 ± 0.06	0.43 ± 0.11	1.25 ± 0.07	0.23 ± 0.13	<0.01
C/N Ratio[c]	20.96 ± 0.11	22.13 ± 0.59	16.52 ± 0.13	14.63 ± 0.27	33.13 ± 6.53
Electrical Conductivity (mS cm^{-1})	1.59 ± 0.19	1.66 ± 0.20	0.23 ± 0.01	0.83 ± 0.07	1.00 ± 0.14
Calcium Carbonate Equivalence (%)	0.89 ± 0.02	0.76 ± 0.03	0.54 ± 0.01	0.50 ± 0.01	0.65 ± 0.04
CEC (cmol(+) kg^{-1})[d]	13.98 ± 0.94	5.02 ± 0.28	10.47 ± 0.15	4.39 ± 0.14	2.11 ± 0.09
Exchangeable Ca (cmol(+) kg^{-1})[d]	19.92 ± 0.29	8.75 ± 0.67	6.33 ± 0.13	5.63 ± 0.23	4.74 ± 0.28
Exchangeable Na (cmol(+) kg^{-1})[d]	0.20 ± 0.02	0.09 ± 0.03	0.07 ± 0.01	0.05 ± 0.02	0.05 ± 0.02
Exchangeable Mg (cmol(+) kg^{-1})[d]	0.68 ± 0.03	0.17 ± 0.01	0.61 ± 0.02	0.14 ± 0.01	0.08 ± 0.01
Exchangeable K (cmol(+) kg^{-1})[d]	0.50 ± 0.13	0.29 ± 0.02	0.32 ± 0.03	0.32 ± 0.03	0.17 ± 0.01

Samples were collected from test plots during the first growing season (August 2009) with the exception of bulk density (n=4), penetration resistance (n=32) and calcium carbonate equivalent (n=16), which were sampled in August 2010.

[a]Total Organic C = Total organic C – Total inorganic C; [b]Soil Organic Matter = Total Organic C x 2.5 for B horizon (Troeh and Thompson, 1993); [c]C/N ratio = Total Carbon/Total Nitrogen; [d]Samples prepared using Neutral Ammonium Acetate.

Plant Performance

In response to the addition of NAG sand to 2- and 10-year old stockpiled topsoil, plant performance was either similar to the performance observed in non-amended topsoils or showed a significant increase (Table 2). When comparing measures of plant performance between NAG sand amended and non-amended topsoils, no difference in percent emergence, seedling density, percent cover or plant height was found. In addition, no difference in percent cover per seedling was observed between NAG sand amended and non-amended 2-year topsoil; however, in 10-year old topsoil, an interaction was observed between seeding treatment and NAG sand as cover per seedling for arctic lupine decreased in response to the addition of NAG sand. Belowground biomass for some seeding treatments was higher in NAG sand amended compared to non-amended topsoils. Furthermore, the shoot:root ratio was shown to be higher in NAG sand amended 2-year old topsoil compared to the non-amended topsoil; the opposite trend was found in 10-year old topsoil. This evidence suggests that the addition of NAG sand to stockpiled topsoils altered the physical properties of topsoil such that conditions for plant growth may have been slightly improved. It is hypothesized that surface temperature, water infiltration and soil aeration (i.e., air-filled porosity) were more favorable for plant establishment and growth in topsoils that were NAG sand amended than those that were non-amended.

Species-Specific Plant Performance

In this experiment, performance differences were observed among three grass species (blue wildrye, Rocky Mountain fescue and fringed brome) and one legume (arctic lupine; data not shown). Growth characteristics observed by the three grass species included high seed germinability, tall stature and dense canopies (which were less apparent with fringed brome and Rocky Mountain fescue) and an ability to quickly utilize and improve access to resources in response to competition with other species (e.g., light and nutrients), leading to high morphological plasticity. In comparison to the grass species, the growth characteristics displayed by arctic lupine included low seed germinability, low stature (in comparison to the grass species), no significant response to competition with other species (i.e., blue wildrye), greater ability to store resources through the use of thick rhizomes and association with nitrogen-fixing *Rhizobium* and low morphological plasticity.

In addition to the differences in plant performance between the grass and legume species, differences in plant performance were also observed between the two varieties of blue wildrye (Table 3). Overall, the blue wildrye mixed genotype had higher mean values for most measures of plant performance compared to the locally specialized genotype (in most cases the differences were significant). There were a few exceptions: the local genotype showed greater mean plant height compared to the mixed genotype for seedlings established in 10-year old topsoil. No difference between the two varieties was observed for belowground biomass in 10-year old topsoil and above- and belowground biomass per seedling in both topsoils. In addition, the local genotype of blue wildrye showed higher mean values for the shoot:root ratio for blue wildrye, established from seeds from a broader geographic area, may be greater than the benefits associated with a narrower genotype supposedly adapted to local soil and climate conditions.

Table 2. Mean values (± SE) of plant growth characteristics collected from all substrate treatments in 2- and 10-year old stockpiled topsoil test plots at the end of the second growing season (September 2010). Mean values represent an average of all single-species seeding treatments.

	Seedling Density (Seedling m^{-2})[a]	**Emergence (%)[a]**	**Plant Height (cm)**	**Cover (%)**	**Cover per Seedling (% $Seedling^{-1}$)[a]**
2-Year Topsoil					
Topsoil	211 ± 13 (n=16)	44 ± 12 (n=16)	23.3 ± 6.4 (n=17)	12 ± 2 (n=20)	0.07 ± 0.02 (n=20)
Topsoil + NAG sand	237 ± 13 (n=16)	46 ± 11 (n=16)	22.4 ± 5.5 (n=17)	16 ± 3 (n=20)	0.10 ± 0.03 (n=20)
Topsoil + Fertilizer	349 ± 19 (n=16)	70 ± 15 (n=16)	36.9 ± 5.0 (n=18)	24 ± 4 (n=20)	0.18 ± 0.08 (n=20)
Topsoil + NAG sand + Fertilizer	314 ± 14 (n=16)	66 ± 13 (n=16)	39.6 ± 6.0 (n=19)	27 ± 4 (n=20)	0.13 ± 0.03 (n=20)
10-Year Topsoil					
Topsoil	238 ± 14 (n=16)	47 ± 13 (n=16)	25.0 ± 3.7 (n=17)	20 ± 3 (n=20)	0.12 ± 0.03 (n=20)
Topsoil + NAG sand	298 ± 16 (n=16)	59 ± 12 (n=16)	31.2 ± 4.5 (n=19)	21 ± 4 (n=20)	0.08 ± 0.01 (n=20)
Topsoil + Fertilizer	342 ± 16 (n=16)	72 ± 13 (n=16)	42.6 ± 5.4 (n=20)	30 ± 5 (n=20)	0.13 ± 0.02 (n=20)
Topsoil + NAG sand + Fertilizer	360 ± 19 (n=16)	77 ± 18 (n=16)	43.6 ± 5.7 (n=18)	31 ± 5 (n=20)	0.08 ± 0.01 (n=20)

	Aboveground Biomass (g m^{-2})	**Aboveground Biomass per Seedling (g $Seedling^{-1}$)[a]**	**Belowground Biomass (g m^{-2})**	**Belowground Biomass per Seedling (g $Seedling^{-1}$)[a]**	**Shoot:Root Ratio**
2-Year Topsoil					
Topsoil	20.5 ± 5.2 (n=16)	0.12 ± 0.03 (n=16)	6.9 ± 2.4 (n=16)	0.05 ± 0.02 (n=16)	4.7 ± 0.7 (n=15)
Topsoil + NAG sand	35.5 ± 9.7 (n=16)	0.17 ± 0.04 (n=16)	30.7 ± 13.9 (n=15)	0.21 ± 0.10 (n=15)	3.5 ± 0.7 (n=13)
Topsoil + Fertilizer	61.2 ± 9.0 (n=16)	0.30 ± 0.10 (n=16)	23.5 ± 10.2 (n=16)	0.21 ± 0.13 (n=16)	5.7 ± 0.6 (n=14)
Topsoil + NAG sand + Fertilizer	113.0 ± 28.5 (n=16)	0.50 ± 0.13 (n=16)	60.9 ± 24.4 (n=16)	0.50 ± 0.26 (n=16)	5.9 ± 1.2 (n=15)
10-Year Topsoil					
Topsoil	34.2 ± 5.7 (n=16)	0.22 ± 0.08 (n=16)	14.8 ± 5.3 (n=16)	0.17 ± 0.10 (n=16)	4.8 ± 0.7 (n=15)
Topsoil + NAG sand	53.4 ± 9.6 (n=16)	0.18 ± 0.03 (n=16)	9.5 ± 2.0 (n=16)	0.07 ± 0.03 (n=16)	5.6 ± 0.7 (n=15)
Topsoil + Fertilizer	100.0 ± 15.5 (n=16)	0.37 ± 0.07 (n=16)	24.9 ± 6.2 (n=16)	0.32 ± 0.13 (n=16)	5.4 ± 0.8 (n=16)
Topsoil + NAG sand + Fertilizer	117.0 ± 21.0 (n=16)	0.23 ± 0.03 (n=16)	14.4 ± 3.4 (n=15)	0.04 ± 0.01 (n=15)	7.1 ± 0.8 (n=13)

[a]Mean values do not include Rocky Mountain fescue due to the difficulty in distinguishing individual seedlings from individual culms.

Table 3. Mean values (±SE) of plant growth characteristics (n=16) for local genotype (local) and mixed genotype (ecovar) blue wildrye in 2- and 10-year old stockpiled topsoil test plots at the end of the second growing season (September 2010).

	2-Year Topsoil		**10-Year Topsoil**	
	local	**ecovar**	**local**	**ecovar**
Seedling Density (Seedlings m^{-2})	419 ± 50	529 ± 33	499 ± 44	560 ± 48
Emergence (%)	60 ± 7	127 ± 8	71 ± 6	135 ± 12
Height (cm)	37.9 ± 6.7	45.7 ± 7.4	51.6 ± 6.0	40.7 ± 6.6
Cover (%)	27.2 ± 3.7	32.9 ± 3.2	40.2 ± 4.5	43.5 ± 3.4
Cover per Seedling (% $Seedling^{-1}$)	0.07 ± 0.01	0.06 ± 0.004	0.08 ± 0.01	0.08 ± 0.01
Aboveground Biomass (g m^{-2})	58.1 ± 11.5	111.5 ± 34.4	99.1 ± 13.5	85.5 ± 10.5
Aboveground Biomass per Seedling (g $seedling^{-1}$)	0.14 ± 0.03	0.21 ± 0.06	0.19 ± 0.02	0.15 ± 0.01
Belowground Biomass (g m^{-2})	8.4 ± 1.2	20.2 ± 4.7	14.7 ± 2.0	15.4 ± 2.7
Belowground Biomass per Seedling (g $seedling^{-1}$)	0.02 ± 0.002	0.04 ± 0.01	0.03 ± 0.003	0.03 ± 0.003
Shoot:Root Ratio	6.3 ± 0.7	5.0 ± 0.6	7.0 ± 0.5	6.0 ± 0.3

CONCLUSIONS AND RECOMMENDATIONS

The findings of this experiment confirm that the application of NAG sand as an amendment to stockpiled topsoil can be used to increase the quantity of growth medium available for reclamation while maintaining plant performance equal to the performance observed in non-amended topsoil. When combined with a fertilizer application, plant performance on topsoils amended with NAG sand can be significantly increased over that of untreated topsoils. The findings also suggest that concentrations of total, exchangeable and extractable trace elements and base metals in NAG sand amended topsoils are not likely to result in any adverse effects to plant growth and the local environment where this treatment is applied. However, the potential effects of amending topsoil with NAG sand to aquatic environments downstream from which this treatment would be applied is unknown. Therefore, it is recommended that the use of NAG sand as an amendment to stockpiled topsoil should be limited to hydrologically isolated areas of the minesite (e.g., tailings impoundments and tailings-filled pits).

When the performance of the three grass and single legume species in this experiment were compared, the two varieties of blue wildrye exhibited the best performance. Therefore, blue wildye is an excellent candidate for the revegetation of stockpiled topsoils at Huckleberry Mine. In terms of seed source, plant performance of blue wildrye established from a mixed genotype seed source (ecovar) performed better than that of the local genotype. However, previous research comparing these two seed sources has shown conflicting results (Burton, 2007). Thus, in order to achieve an optimal cover of blue wildrye, the best result may come from the use of seed stocks which are composed of both genotypes.

Plant establishment and productivity in 10-year old topsoil appears to be greater than establishment and productivity in the 2-year old topsoil (although this difference is not statistically demonstrable). This result is most apparent when comparing percent cover and height of plants established in the two different-aged topsoils. Assuming the effects of elevation and climate differences between the locations of 2- and 10-year old stockpiled topsoil test plots are negligible, physical and chemical conditions in the

10-year old stockpiled topsoil are likely to be more conducive to plant growth. It is hypothesized that the considerably greater amount of volunteer vegetation cover that had established on the 10-year old stockpiles in comparison to the 2-year old stockpiles of topsoil may have resulted in greater cumulative biological contributions to the soil material. This interpretation is supported by observations of greater soil organic matter (SOM), ammonium, mineralizable N and total N (data not shown) in 10-year old compared to 2-year old topsoil.

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