FIELD TRIALS ON USE OF BIOCHAR VERSUS PEAT FOR LAND RECLAMATION PURPOSES

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ABSTRACT
Biochar application for revegetation purposes in northern Saskatchewan was studied to determine its effectiveness as a soil amendment in establishing sustainable vegetative soil covers. The abandoned Gunnar Mine Site, located on the northern shore of Lake Athabasca, served as a study area to test the effectiveness of biochar as a soil amendment. Field trials were carried out to compare the effect of biochar and peat application on the growth and establishment of native plant species. The field trials showed that peat promotes vegetation cover establishment better than biochar. Biochar also had a positive effect on vegetation recovery through both establishment of seeded plants and self-establishment of natural invaders (plant species not seeded during the experiment). Peat and biochar had different effects as soil amendments, depending on the plant species. It was shown that both peat and biochar can be used to promote plant establishment and growth, but biochar effectiveness may vary depending on its properties.

KEY WORDS
Revegetation, Native Boreal Species, Organic Amendment, Mineral Fertilizer, Soil

INTRODUCTION
The establishment of vegetation cover on disturbed mine sites is an important task of mine closure to protect the soil surface from wind and water erosion, to restore wildlife habitats, and to create opportunities for sustainable development of local Aboriginal communities. Properties of growth media is a significant factor of the revegetation success. In northern environments, fertile soil layer (topsoil) is often very thin, with low organic matter and nutrient contents. Topsoil also can be easily lost as a result of mining activities. Therefore, soil organic amendments and mineral fertilizers are often applied to improve soil properties and increase effectiveness of revegetation activities. Transportation of organic media to remote northern sites is very expensive because of their low bulk density, whereas local harvesting for organic materials (usually peat) destroys natural wetlands which are valuable natural habitat. As a result,
there is an emerging need for alternative organic soil amendments to avoid costs associated with material transport, while minimizing detrimental impacts to wetland habitats.

Biochar is a solid material obtained from the carbonisation of biomass through pyrolysis that can be used as a soil amendment to improve its chemical and physical properties (Lehman and Joseph 2009; Verheijen et al. 2009). In addition, biochar application has been shown to create favorable conditions for soil microbiota, promote plant growth, and increase plant resistance to disease (Verheijen et al. 2009; Biederman and Harpole 2012; Elad et al. 2012). Therefore, this organic amendment can be beneficial for establishment of sustainable vegetative covers on soils. Potentially, biochar can be produced on-site or in nearby communities from local feedstock (e.g. organic wastes), which makes it a promising substitute for conventional organic amendments (Roberts et al. 2009). On the other hand, most biochar research is focused on its effect on cultivated crops and few studies consider its benefit to establishing native plant species (Elad et al. 2012; Adams et al. 2013; Sovu et al. 2013). Thus, there is still no unanimous opinion regarding the applicability of biochar to establish vegetative covers and which trades off can be associated with its application.

The purpose of this research was to test the effectiveness of biochar as a soil amendment for mine site remediation in northern Saskatchewan. The Gunnar Mine Site, located on the northern shore of Lake Athabasca, was selected as a study site for the research, since one of the project tasks is to establish self-sustaining vegetation on engineered covers that are to be installed over the Gunnar tailings deposits (SRC 2014). The cover (borrow) material, which will likely be taken from the local airstrip and neighboring areas, is coarse sand with gravel inclusions, that has a very low organic matter content (less than 0.1%), and a limited capacity to support plant establishment and growth. As a result, application of organic amendments and mineral fertilizer will be necessary to enhance its properties as a growth medium. In 2011, two organic amendments (peat and biochar) and mineral fertilizer were tested in a greenhouse to study the response of native plant species to various soil amendments and treatments. It was shown that both peat and biochar boost plant establishment and growth, but the response differs between plant species (Petelina et al., 2014). The greenhouse trails were carried out with isolated species; and obtained results had a limited validity in relation to effect of soil treatment on establishment of desired plant community under natural conditions. Therefore, it was decided to run field trails at the Gunnar Mine Site.

**METHODS**

The field trials involved the sowing of a native species seed mix on different combinations of borrow material, two soil organic amendments (three rates), and mineral fertilizer (two rates). The experiment had a factorial design, with 4 replicates of each combination of borrow material with organic amendment or/and mineral fertilizer.

The study area is located within the Taiga Shield Ecozone and the Tazin Lake Upland Ecoregion. The trials were set up along the periphery of the Gunnar airstrip in mid-June 2012. Before the trial set up, the research area was cleared of vegetation. Due to high compaction of the airstrip material and high content (up to 50% by volume) of big stones in it, 7 wooden bottomless boxes (frames) were constructed for the experiment. Each box was 0.3 m x 4 m x 6 m and was divided into twelve 1.5 m x 1.5 m cells. The boxes
were half-buried below the soil surface. One box was filled with pure borrow material and six boxes were filled with mixture of borrow material with two organic amendments at three different rates. Boxes for the soil mixtures were assigned on a random basis.

Borrow material for the trials was collected from a borrow area along the periphery of the airstrip near Gunnar. The borrow material was sampled at the depth below 20 cm to exclude top soil with the seed bank from the experiment. The borrow material was poor in organic carbon, nitrogen, plant available phosphorus, and potassium, and was composed mostly of sand, with a high inclusion of gravel and big stones, and poor in silt and clay. Prior to the trial start-up the borrow material was screened through 5 cm steel mesh to exclude large stones.

Sphagnum peat and pine chunky biochar were used as organic amendments for the field trials. Both peat and biochar were purchased from commercial suppliers. Both types of organic amendments had low contents of plant available nitrogen, phosphorus, potassium, and sulfur. Organic matter content was higher in the peat than in the biochar (94% vs. 78%, respectively). Water holding capacities of the peat and biochar were 523% and 68%, respectively. The application rate of organic amendments was targeted to achieve 2, 4 and 6% of organic matter in the soil mixture, corresponding to application rates for organic amendments of 80, 160, and 240 t/ha of peat (hereafter, peat rates are referred as “peat at low, medium, or high rate”), and 90, 190, and 280 t/ha of biochar (hereafter, biochar rates are referred to as “biochar at low, medium, or high rate”).

After the boxes were filled with soil treatments, as described above, native plants were seeded by hand broadcasting on 1 m² plots placed in the centre of each of the box cells. The seed mixture was comprised eight grasses, five forbs, and one shrub. Its composition in percentage of pure live seeds by weight was as follows:

- Rocky Mountain Fescue (*Festuca saximontana*) – 20%
- American Vetch (*Vicia americana*) – 20%
- Streambank Wheatgrass (*Elymus lanceolatus ssp. riparius*) – 10%
- Slender Wheatgrass (*Elymus trachycaulus*) – 10%
- Violet Wheatgrass (*Elymus violaceus*) – 10%
- Tufted Hairgrass (*Deschampsia caespitosa*) – 7%
- Rough Hair Grass (*Agrostis scabra*) – 7%
- Canada Buffaloberry (*Shepherdia canadensis*) – 6%
- Canadian Milkvetch (*Astragalus Canadensis*) – 4%
- Marsh Reed Grass (*Calamagrostis canadensis*) – 3%
- White Bluegrass (*Poa glauca*) – 1%
- Alpine Milkvetch (*Astragalus alpinus*) – 1%
- Prairie Crocus (*Anemone patens*) – 1%
- Fireweed (*Chamerion angustifolium*) – 0.1%

The seeding rate was 2000 PLS/m² or 15.6 PLS kg/ha.
After seeding, the mineral fertilizer was applied by the hand broadcasting. Fertilizer rates were designed in line with the lowest and highest agronomic rates recommended by the Saskatchewan Forage Council for slender wheatgrass cultivation (SFC, 1998). The low fertilizer rate was 22 N kg/ha, 56 P$_2$O$_5$ kg /ha, 56 K$_2$O kg/ha, and 10 S kg /ha. The high fertilizer rate was 45 N kg/ha, 84 P$_2$O$_5$ kg /ha, 112 K$_2$O kg/ha, and 20 S kg/ha. Plots for fertilizer application were assigned within each box on a random basis.

A vegetation survey of the trial plots was carried out two months after seeding. For each sampling quadrat, the vegetation cover was assessed using the modified Daubenmire method (Bailey and Poulton, 1968). As vegetation on the plots was presented by both seeded plants and natural invaders, the effectiveness of soil treatments was assessed on the basis of their impact on total vegetation cover (TVC), seeded plant cover (SPC) and cover of dominant invaders (i.e., rough cinquefoil and strawberry blite). The Kruskal-Wallis test, followed by the Conover-Iman procedure, were used to assess the statistical significance of the response of the investigated indices to the soil treatments using XLSTAT for all data groups. The significance level for all tests was 0.05.

RESULTS

Two months after the trial start-up, vegetation was observed on all the plots. A total of 30 vascular plant species were found within the overall research area (all plots together; Table 1). Of this total, 14 species were seeded during the trial startup and 16 species were natural invaders that got to the plots with the borrow material or were transported from nearby areas by wind.

Figure 1 shows the total vegetation cover (TVC), seeded plant cover (SPC), rough cinquefoil cover (RCC) and strawberry blite cover (SBC) on the tested soil mixtures.

Plant establishment on the borrow material without any amendments (control) was very poor (TVC=2%, SPC=0.5%, RCC=0.4%, and SBC=0.3% on average). Organic amendments alone had very low or no impact on plant establishment (the average increment of TVC did not exceed 6% for biochar and 4% for peat). Fertilizer alone applied at the high rate promoted plant establishment to a larger extent than organic amendments (the average increment of TVC was 16%).

In comparison with the control, peat/fertilizer combinations had the strongest positive impact on TVC, SPC, and RCC. All three indexes were the highest when:
- peat at the low rate was combined with fertilizer at the high rate (TVC=33%, p<0.001; SPC=10%, p<0.001; RCC=15%, p<0.001)
- peat at the medium rate was combined with fertilizer at the high rate (TVC=39%, p<0.001; SPC=10%, p<0.001; RCC=15%, p<0.001)
- peat at the high rate was combined with fertilizer at the low rate (TVC=44%, p<0.001; SPC=8%, p<0.001; RCC=44%, p<0.001) and the high rate (TVC=28%, p<0.001; SPC=10%, p<0.001; RCC=25%, p<0.001).

There was no statistically significant difference for TVC, SPC, and RCC data for the above treatments (p varied from 0.059 to 0.761).
Table 1. List of plant species observed during the field trials.

<table>
<thead>
<tr>
<th>Seeded Species</th>
<th>Invading species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scientific Name</strong></td>
<td><strong>English Name</strong></td>
</tr>
<tr>
<td>Agrostis scabra</td>
<td>rough hair grass</td>
</tr>
<tr>
<td>Astragalus alpinus</td>
<td>alpine milkvetch</td>
</tr>
<tr>
<td>Astragalus Canadensis</td>
<td>Canada milkvetch</td>
</tr>
<tr>
<td>Brassica napus</td>
<td>canola</td>
</tr>
<tr>
<td>Calamagrostis canadensis</td>
<td>marsh reed grass</td>
</tr>
<tr>
<td>Chamerion angustifolium</td>
<td>fireweed</td>
</tr>
<tr>
<td>Deschampsia cespitosa</td>
<td>tufted hairgrass</td>
</tr>
<tr>
<td>Elymus trachycaulus</td>
<td>slender wheatgrass</td>
</tr>
<tr>
<td>Elymus lanceolatus ssp. riparius</td>
<td>streambank wheatgrass</td>
</tr>
<tr>
<td>Elymus violaceus</td>
<td>violet wheatgrass</td>
</tr>
<tr>
<td>Festuca saximontana</td>
<td>rocky mountain fescue</td>
</tr>
<tr>
<td>Species</td>
<td>Common Name</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td><em>Poa glauca</em></td>
<td>white bluegrass</td>
</tr>
<tr>
<td><em>Shepherdia canadensis</em></td>
<td>Canada buffaloberry</td>
</tr>
<tr>
<td><em>Vicia americana</em></td>
<td>American vetch</td>
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*- seeded by accident
Figure 1. Effect of mineral fertilizer, biochar, and peat on the total vegetation cover (a), seeded plant cover (b), rough cinquefoil cover (c), and strawberry blite cover (d), for field trials. Error bars indicate standard deviation (absence of error bar means that the standard deviation is zero). BM – borrow material; B, low/med/high – biochar added at low/medium/high rate; P, low/med/high – peat added at low/medium/high rate.

All biochar/fertilizer treatments increased SBC, while peat application did not affect this parameter. SBC varied from 1% on the plots with biochar at the high rate and fertilizer at the low rate to 13% on the plots with biochar at the low rate and fertilizer at high rate, which is significantly higher compared to control plots (p=0.001 and p<0.001, respectively). Biochar/fertilizer combinations also promoted TVC (up to 13%), SPC (up to 3%), and RCC (up to 4%), but these effects were significantly lower than effects from the above peat/fertilizer treatments (p < 0.001 in all cases).

Interestingly, when biochar was applied alone, the increase of its rate from low to high resulted in a significant decrease of TVC (from 6 to 2%, p<0.001), SPC (from 3 to 1%, p=0.006) and SCC (from 6 to...
When biochar was applied with fertilizer at the low rate, the same trend was observed, only for TVC. TVC decreased from 8 to 2\% when the biochar rate was increased from low to high (p<0.001). There was no significant difference between the indexes when biochar at different rates was applied with fertilizer at the high rate (p varied from 0.092 to 1.000).

**DISCUSSION AND CONCLUSION**

Both biochar and peat promoted establishment of vegetation, but peat appeared to be more effective than biochar. The better performance of peat as an organic amendment is likely due to its high water holding and sorption capacity. Water holding capacity of the peat was eight times higher than that of the biochar; therefore, borrow material mixed with peat had a higher propensity to retain water and nutrients compared to the same rate with biochar. Peat also had a finer structure than chunky biochar, and borrow/peat mixtures were more homogenous than the soils amended with comparable rates of biochar.

Invader species abundance was different in plant communities grown without organic amendments versus with peat and biochar (e.g. rough cinquefoil dominated on the plots with peat and strawberry blite dominated on the plots with biochar). As the borrow material for the trials was taken from the same borrow area and boxes were placed and filled randomly, the observed difference in the species composition depended on treatment and species features with respect to their soil specialization. As peat had higher ability to hold and retain water and nutrients than biochar, therefore, its presence in the borrow material was more favorable for those plants normally growing in wetter areas, such as rough cinquefoil, tufted hairgrass, and other native grasses (e.g. marsh reed grass or streambank wheatgrass). Faster development of all these plant species under favorable conditions made them stronger competitors, i.e. they could develop faster than other species, impeding their development. Biochar addition to the borrow material also improved its properties, but to a lesser degree than peat (the water holding capacity of the biochar+borrow mixtures was approximately two-fold lower than that of the peat/borrow mixtures). Those plant species adapted for moist conditions were less competitive than other species on the soils with biochar. Thus, biochar addition to the borrow material created more favorable conditions for ruderal species such as strawberry blite, annual hawksbeard, reflexed rockcress, and sagewort wormwood, all known as pioneer species on disturbed areas with relatively low water and nutrient content.

It should be noted that higher rates of biochar had a negative impact on vegetation establishment and development. This phenomenon is in line with the results of other researchers who suggested an idea of “biochar loading capacity” (Verheijen et al., 2009). Biochar loading capacity (BLC) is the maximum amount of biochar that can be added to the soil without compromising its other properties and impeding plant growth. BLC can vary from a few tens to a few hundreds of tonnes per hectare, depending on soil properties, biochar properties and plant species. In our case, BLC is likely to be within the interval of 90 to 190 tonnes of biochar per hectare and increases in proportion to fertilizer rates.

Although both biochar and peat treatments showed a significant positive impact on plant establishment, peat is likely to be a more suitable organic amendment for the future revegetation at the Gunnar Mine Site.
The purpose of the Gunnar project is to establish vegetation cover which meets the following requirements:

- to ensure erosion protection of the engineering cover on the tailings areas;
- to impede the establishment of trees and shrubs, which could damage the cover due to penetration by roots and could bring contaminated groundwater to the surface via root transport;
- to be self-sustaining, i.e. able to persist for a long time without additional maintenance; and
- to minimize presence of exotic species to the lowest practicable level.

To meet the first and second requirements, the vegetation cover should cover at least 30-40% in the first year after seeding (Matheus and Omtzigt, 2012). Our results show that this requirement is achievable when the seed mixture is applied at a rate of 2000 PLS/m², and when seeded on soils amended with both peat and fertilizer, which in our case corresponded to the following treatments:

- peat at any rate (i.e. 80, 160, or 240 tonnes/ha) with fertilizer at the high rate (i.e. 45 N kg/ha, 84 P2O5 kg/ha, 112 K2O kg/ha, and 20 S kg/ha), or
- peat at high rate (i.e. 240 tonnes/ha) with fertilizer at the low rate (i.e. 22 N kg/ha, 56 P2O5 kg/ha, 56 K2O kg/ha, and 10 S kg/ha).

The above treatments also are beneficial to comply with the third and fourth requirements of the Gunnar project for the following reasons:

- The tallest grasses and the highest frequency of mature tufted hairgrass and wheatgrass were also observed at the above treatments. This suggests that plant communities for these treatments have the highest chances to be self-sustaining without additional investments.
- As discussed above, peat promotes the establishment of native plants, thereby increasing the plant community resilience to exotic species invasion.

In conclusion, it must be emphasised that the above results and recommendation are based on a single year of trials and should be used with caution for the following reasons:

- All the trial plant species are perennial, and one year is not adequate for most of the species to gain maturity. Until we have evidence that most seeded plants have reached maturity and started reproduction, we cannot make a decisive conclusion about self-sustainability of the newly established plant communities.
- Some species that emerged on the plots may not survive the harsh Gunnar winter; therefore, the plant winter hardiness should be also tested.
- The revegetation trials have been affected by the unusually wet conditions in July, 2012. Excessive watering of the trial plots after seeding could promote emergence, survival, and establishment of the seeded plants. It may also be particularly true for the plants associated with wetter conditions. Long-term observations of the plots will help to define which plant species were affected by the extreme weather conditions and which of them can persist under site-specific conditions at Gunnar.
- The species composition of the newly established plant community may change drastically with time, e.g. due to fertilizer depletion or exotic species invasion; therefore, longer-term observations are required to determine which revegetation technique is most successful for establishment of a self-sustaining and resilient ecosystem over the longer term.
Thus, monitoring of the trial plots should be continued for a few year to make conclusive recommendations for a larger scale revegetation effort at the Gunnar Mine Site.

ACKNOWLEDGMENTS

Funds required for this work were provided by SRC under the CLEANS project. We wish to thank our colleagues Bob Godwin, Mary Moody, Miguel Providenti, and Jeff Thorpe for their advice and useful discussions during the development of the project design and the interpretation of results. Our special thanks to Shasta Lysohirka and Michael Bendzsak (SRC), who assisted in the field during the experiment set up and data gathering.

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