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

Elizaveta Petelina, B.Sc., MSEM[1]
Alexey Klyashtorin, Ph.D[2]
Tamara Yankovich, Ph.D[3]

[1]Remediation Specialist
[2] Senior Environmental Scientist
Saskatchewan Research Council, Saskatoon, Canada

[3]Radiation Protection Specialist
International Atomic Energy Agency, Vienna, Austria

ABSTRACT

Experimental testing has been conducted to determine the effect of amendment of soil with mineral fertilizer, biochar, and peat on emergence, survival, establishment, and productivity of northern boreal plant species grown on poor substrates in a controlled environment (in greenhouse). Four species (slender wheatgrass, rocky mountain fescue, American vetch, and common yarrow) were grown in pots containing poor sandy soil amended with mineral fertilizer and/or organic amendments (peat or biochar). The greenhouse temperature, lighting and pot watering regimes simulated the conditions of vegetation growing season in northern boreal forest. The trials showed that mineral fertilizer had a limited ability to promote plant growth compared to peat and biochar. Both types of organic amendments had similar positive effects on the establishment of two test species (American vetch and common yarrow) and on the growth of three test species (slender wheatgrass, rocky mountain fescue and American vetch). Peat had a stronger positive effect on emergence of slender wheatgrass and establishment of rocky mountain, while biochar promoted the common yarrow growth better than peat.

KEY WORDS
Revegetation, native boreal species, organic amendment, mineral fertilizer, soil

INTRODUCTION

Revegetation is a final stage of any land reclamation project aimed at provision of both wildlife habitat and long-term erosion control. In this respect, ideally, the vegetation cover will consist of native plant species, perform its ecosystem functions, and be self-sustaining, i.e. cover not require additional treatment after the plant community reaches its steady state; however, pursuing such an ambitious goal at disturbed sites in a boreal zone may face serious challenges, such as limited knowledge of the ability of plant species to recover quickly under harsh climatic conditions, and poor physical and chemical properties of growth media (Mining Watch Canada, 2001; Daniels and Zipper, 2010; Landline et al., 2011).

The purpose of this research was to run greenhouse trials using native boreal species and various soil amendments for application in disturbed areas at the Gunnar Mine Site, an abandoned uranium mine/mill site located on the northern shore of the Athabasca Lake and managed by the Saskatchewan Research Council (SRC). One of the project tasks is to establish self-sustaining vegetation on the engineered cover over tailings (SRC, 2014). The cover material is to be taken from the local airstrip and neighboring areas. The proposed borrow material is coarse sand with gravel inclusions and very low organic matter content (less than 0.1%), and has a limited capacity to support vegetation growth. It was recognized recently that biochar (a byproduct of pyrolysis) could promote soil fertility (Verheijen et al. 2009; Biederman and Harpole 2012; Adams et al. 2013), so it was decided to test the effectiveness of biochar, along with conventional soil conditioners (i.e. mineral fertilizer and peat), to promote establishment of vegetation.

METHODS

The greenhouse trials involved growing four plant species (i.e. Slender Wheatgrass (*Elymus trachycaulus*), Rocky Mountain Fescue (*Festuca saximontana*), American Vetch (*Vicia americana*), Common Yarrow (*Achillea millefolium*)) in pots containing combinations of borrow material collected in the vicinity of the Gunnar Mine Site with mineral fertilizer and two organic amendments (peat and biochar) (treatments are listed in Table 1). The experiment had a randomized design with five replicates of each soil mixture and plant species.

Borrow material for the trials was collected from the borrow area at the Gunnar airstrip. The borrow material was sampled from the depth below 20 cm to exclude top soil with its seed bank from the experiment. The borrow material was poor in organic carbon, nitrogen, and plant available phosphorus and potassium. It was poor in silt and clay, and composed mostly of coarse sand with a high proportion of gravel and big stones. Prior to the trial start-up, the borrow material was sieved through 1-cm sieves to remove the stones.

Sphagnum peat and willow dust biochar were used as organic amendments for the greenhouse 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. The organic matter content was higher in peat compared to biochar (93% vs. 76%, respectively), and the water holding capacity of the peat was 509%, while that of the biochar was 454%. The application rate of organic amendments was targeted to comprise 2% of the organic matter in the soil mixture, so the application rates for peat and biochar were 80 t/ha and 95 t/ha, respectively.

Borrow material and organic amendments were mixed by hand and used to fill 2 L pots (18 cm in diameter). All the pots were placed in an enclosed greenhouse in random order. The greenhouse conditions were adjusted to the Gunnar average monthly temperature during the vegetation growing season (i.e., average air temperature of 20ºC during the 16 hours of light and average air temperature of 10ºC during the 8 hours of darkness). The photoperiod was maintained at 16 hours of light and 8 hours of darkness.

Seeds for the greenhouse trials were obtained from commercial seed suppliers. Burton and Burton's (2003) recommendations on growing selected plant species were used as a basis for seeding rates and seeding depth, as follows:

- Slender Wheat Grass – 6 pure live seeds (PLS) per pot at the depth of 1.5 cm;
- Rocky Mountain Fescue – 22 PLS per pot at the depth of 1 cm;
- American Vetch – 4 PLS per pot at the depth of 1 cm; and
- Common Yarrow – 11 PLS per pot on the soil surface.

Before seeding, all pots were excessively watered to imitate spring snowmelt conditions, and fertilizer was applied to the corresponding pots after seeding. Saskatchewan Forage Council (SFC, 1998) recommendations on slender wheatgrass cultivation were used as a basis for fertilizer rates, which were 45 N kg/ha, 84 P2O5 kg /ha, and 112 K2O kg/ha for soils with poor nutrient content.

The trial time period was 12 weeks, which is close to the vegetation growing season at Gunnar. During the trial period, the pots were rotated weekly to avoid the edge effect, and were watered every third day at a rate imitating the northern Saskatchewan average monthly precipitation that varies from 38 mm (week 1-4) to 53 mm (week 5-12) (SRC, 2014). During the trials, the seedling number in every pot was measured weekly. In the third week of the trials, it was noticed that direct sunlight might overheat the soil mixtures with biochar because of its black color, impeding seed germination and growth. To avoid such undesirable effects, the greenhouse shades were closed. No other changes in temperature or the water regime were made. At the end of the experiment, the aboveground biomass from each pot was harvested, dried, and weighed.

The experimental data were further processed and analyzed to quantify the following indices: plant establishment rate, seedling emergence rate, seedling survival rate, and aboveground biomass dry weight. All data were tested for normality using the Shapiro-Wilk test. If data did not fit a normal distribution, the Kruskal-Wallis test, followed by the Conover-Iman test, were used to assess statistical differences in the response of the investigated indices to the soil treatments. If data were normally distributed, analysis of variance (ANOVA), followed by the Tukey's HSD (honestly significant difference) test, were run using the XLSTAT statistics program for all data groups. The significance level for all tests was 0.05.

RESULTS

Table 1 provides information on statistically significant effects of soil amendment application on the aboveground biomass dry weight (ABDW), seedling emergence rate (SER), seedling survival rate (SSR), and plant establishment rate (PER) for each plant species grown on the test soil mixtures.

Addition of mineral fertilizer to the borrow material promoted growth of slender wheatgrass, increasing ABDW by a factor of 1.6 (from 62 to 110 mg per pot; p=0.036), but had no effect on the growth of other plant species (p varied from 0.065 to 0.258, depending on the species). This treatment also fostered seedling survival of American vetch, increasing SSR by a factor of 1.7 (from 35 to 59%; p=0.048), yet its impact on SER was not strong enough (p=0.432) to provide a statistically significant overall positive effect on the PER (p=0.843). There was no significant effect of fertilizer application on PER, SER, or

SSR of the other three plant species (p varied from 0.144 to 0.977, depending on the index and plant species).

Addition of peat to the borrow material fostered growth of all four plant species, increasing ABDW by a factor of 3 for slender wheatgrass (from 62 to 209 mg per pot; p<0.001), 6 for rocky mountain fescue (from 62 to 373 mg per pot; p<0.001), 14 for American vetch (from 8 to 111 mg per pot; p<0.001), and 73 for common yarrow (from 2 to 131 mg per pot; p<0.0001). This treatment had an overall positive effect on establishment of rocky mountain fescue and common yarrow, resulting in an increase in SER by a factor of 1.2 (p=0.001) for rocky mountain fescue and 2 (p=0.001) for common yarrow. SSR increased by a factor of 1.3 (p<0.001) for rocky mountain fescue and 8 (p<0.001) for common yarrow, while PER increased by a factor of 1.6 (p<0.001) for rocky mountain fescue and 19 (p<0.001) for common yarrow. The favorable effect of peat on American vetch resulted in an increase in the SSR by a factor of 3 (p<0.001) and PER by a factor of 4 (p=0.001). There was no significant effect of peat application on slender wheatgrass SER (p=0.602), SSR (p=0.532), or PER (p=0.974).

Biochar addition to the borrow material fostered the growth of all four plant species, increasing ABDW by a factor of 4 for slender wheatgrass (from 62 to 265 mg per pot; p<0.001), 8 for rocky mountain fescue (from 62 to 465 mg per pot; p<0.001), 20 for American vetch (from 8 to 161 mg per pot; p<0.001), and 121 for common yarrow (from 2 to 218 mg per pot; p<0.001). This treatment also promoted common yarrow seedling emergence and seedling survival, increasing SER and SSR by factors of 1.7 (from 39 to 66%; p=0.037) and 9 (from 11 to 96; p<0.001), respectively, which resulted in an increase of PER by a factor of 16 (from 4 to 63%; p<0.001). The favorable effect of biochar on mountain fescue and American vetch resulted in increases in SSR by factors of 1.3 (from 77 to 99%; p<0.001) and 3 (from 35 to 100%; p<0.001), respectively, for these species, which resulted in an increase in PER by a factor of 1.2 (from 59 to 73%; p=0.013) for rocky mountain fescue and 4 (from 13 to 49%; p=0.001) for American vetch. Biochar application, however, impeded slender wheatgrass SER, decreasing SER by a factor of 1.3 (from 87 to 69%; p=0.006), yet it had no pronounced effect on the SSR (p=0.532) or PER (p=0.107).

In general, a favorable effect of organic amendments on the investigated plant species was more pronounced than the effect of mineral fertilizer, except for the following cases:

- Peat and mineral fertilizer had similar effects on slender wheatgrass seedling emergence, seedling survival, and plant establishment (p=0.498, 0.454, and 0.974, respectively) and American vetch seedling emergence (p=0.229)
- Biochar and mineral fertilizer had similar effects on seedling emergence of American vetch and common yarrow (p=0.229 and 0.149, respectively) and seedling survival of slender wheatgrass (p=0.393).

Table 1. Statistically significant effects of various soil treatments on plant establishment and biomass ($p<0.05$)

Compared soil mixtures	Ratio between the mean index values															
	Plant establishment rate, %				Seedling emergence rate, %				Seedling survival rate, %				Aboveground biomass dry weight, mg per pot			
	SW*	RMF	AV	CY	SW	RMF	AV	CY	SW	RMF	AV	CY	SW	RMF	AV	CY
BM-NPK : BM-control	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	59:35	n/a	100:62	n/a	n/a	n/a
BM-Peat : BM-control	n/a	94:59	49:13	75:4	n/a	94:78	n/a	87:39	n/a	98:77	100:35	86:11	209:62	373:62	111:8	131:2
BM-Biochar : BM-control	n/a	73:59	49:13	63:4	69:87	n/a	n/a	66:39	n/a	99:77	100:35	96:11	265:62	465:62	161:8	218:2
BM-Peat : BM-Biochar	90:69	94:73	n/a	n/a	90:69	94:74	n/a	n/a	n/a	n/a	n/a	86:96	n/a	n/a	n/a	131:218

* SW – slender wheatgrass; RMF – rocky mountain fescue; AV – American vetch; CY – common yarrow; BM – borrow material; NPK – mineral fertilizer

A summary of the effects of amendment of soil with peat and biochar on the tested plant species is as follows:

- Both amendments had similar effects on the establishment of American vetch and common yarrow (p=1 and 0.136, respectively), and on the growth of slender wheatgrass, rocky mountain fescue and American vetch (p=0.657, 0.288, and 0.165, respectively)
- Peat addition to the borrow material resulted in greater establishment of rocky mountain fescue, in comparison with the biochar addition (94% on peat vs. 73% on biochar; p=0.001)
- Biochar addition to the borrow material resulted in higher ABDW of common yarrow than addition of peat (218 mg per pot on biochar, compared to 131 mg per pot on peat; p=0.014)
- Biochar addition to the borrow material had a negative effect on the SER of slender wheatgrass, while peat addition did not affect this index (87% on borrow material, compared to 90% on peat, and 71% on biochar; p=0.002 for peat compared to biochar).

DISCUSSION AND CONCLUSION

The greenhouse trials demonstrated that mineral fertilizer had a limited ability to promote growth of boreal plant species, which is likely due to the low water holding capacity of the growing media (borrow material). Addition of mineral fertilizer only increased the amount of nutrients in the soil and did not improve water availability; therefore, plants did not improve, as a result.

Conversely, addition of organic amendments had a much more pronounced effect. Study results suggested that biochar could be a good substitute for peat as a soil amendment agent. Also, peat and biochar had different effects on the establishment and growth of different plant species. Establishment of rocky mountain fescue was promoted by peat application to the larger extent than by biochar, but growth of common yarrow was fostered by biochar application to the larger extent than by peat.

The establishment of slender wheatgrass was impeded by biochar application. This “negative” impact of biochar on seedling emergence can be explained by a darker coloration of the biochar-amended soil, which may have caused soil overheating when exposed to direct sunlight, compared to other test materials, which were lighter in color (borrow was yellowish and peat was brown). This could result in both increased seed embryo mortality, and increased evaporation from the borrow material and biochar mixture, which prevented seed germination and increased seedling mortality due to soil desiccation. It is likely that the biochar performance, in terms of plant establishment, could be improved by mulching the soil surface.

Although the trial results were positive, the final choice of a preferred organic amendment can only be made with consideration of the following aspects:

- Although greenhouse trials provide some general indication of the plant response to tested soil treatments, they are not sufficient to draw a definitive conclusion regarding the impact of soil amendment on plant growth and reproduction; to overcome this uncertainty, it is essential to conduct field trials under the Gunnar Mine Site conditions.

- The above-mentioned response of individual plant species to soil amendment will not necessarily be the same or similar to the response of a desired plant community; therefore, it is necessary to perform field trials using seed mixtures.
- Only one rate of mineral fertilizer was tested for each combination of soil and organic amendment. Additional trials should be run using different rates of mineral fertilizer to optimize the fertilizer rates and combinations.

In conclusion, although useful results have been achieved through greenhouse testing, complementary field trials are necessary to compare the soil treatment options under natural conditions, and a feasibility study should be undertaken to compare biochar versus peat as organic amendments.

ACKNOWLEDGMENTS

Funds required for this work were provided by SRC under CLEANS project. We wish to thank our colleagues Bob Godwin, Mary Moody, Miguel Providenti, and Jeff Thorpe for their advice and useful discussions during development of the project design and result interpretation. We are grateful to Dawn Bolin and Roxanne Suchan (SRC) for their help during the greenhouse trials. And we would like to single out David Telfer (TSM Telfer Seed Marketing) who kindly gifted seeds for our greenhouse trials.

REFERENCES

Adams M.M., T.J. Benjamin, N. C. Emery, S. J. Brouder and K. D. Gibson. 2013. The effect of biochar on native and invasive prairie plant species. Invasive Plant Science and Management 6(2): 197-207.

Biederman, L.A. and W.S. Harpole. 2012. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. GCB Bioenergy, 5: 202-214.

Burton, C.M., and P.J. Burton. 2003. A Manual for Growing and Using Seed from Herbaceous Plants Native to the Interior of Northern British Columbia. Symbios Research & Restoration, Smithers, B.C. 168 p.

Daniels, W.L. and C. E. Zipper. 2010. Creation and management of productive minesoils. Virginia Cooperative Extension (VCE) publications. www.ext.vt.edu

Landine, P., D. Fenske, and R. Van Stone. 2011. Thirty years of revegetation experience at the Key Lake uranium mine in northern Saskatchewan. In: Bourie, A.B., M. Tibbett, and A. Beersing (eds.). Mine Closure 2011: Vol. 1 (pp. 47-56). Nedlands: Australian Centre for Geomechanics. 646 p.

MiningWatch Canada. 2001. Mining in remote areas: Issues and impacts -- A community primer. 36 p. http://www.mwatch.koumbit.org

SFC (Saskatchewan Forage Council). 1998. Seed production of Slender Wheatgrass. 12pp.

SRC (Saskatchewan Research Council). 2014. Gunnar site remediation project, environmental impact statement. SRC publication, Saskatoon, SK. 920 pp.

Verheijen, F., S. Jeffery. A.C. Bastos, M. van der Velde, and I. Diafas. 2009. Biochar Application to Soils - A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. EUR 24099 EN, Office for the Official Publications of the European Communities, Luxembourg, 149pp.