CAN FAST-GROWING PLANTATIONS FACILITATE FOREST TREE RECRUITMENT WHILE LIMITING SOIL EROSION IN MINE WASTE ROCK SLOPES?

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Introduction

In forested regions, mine wastes are poor quality substrates for tree establishment, especially waste rocks. Waste rocks are one of the two main solid mine wastes produced by mine sites, along with mill tailings. They come from the rock materials surrounding the ore, which are extracted by explosion and stockpiled on tens of meters (Brooks, 1990). Tree plantation after soil layering could catalyze plant succession on waste rock slopes and accelerate the conversion of revegetated waste rocks into forest, restoring the traditional use of closed mine sites. But in waste rock slopes, soil erosion may limit revegetation success. Herbaceous species are seeded in waste rock slopes to rapidly stabilize soil surface and to limit soil erosion (Helm, 1995). However, used herbaceous species often compete for water, nutrients, and light with planted trees (Rizza et al., 2007; Franklin et al., 2012), and are low quality nurse plants to allow natural colonization of revegetated slopes by forest trees. On the contrary, the use of fast-growing tree plantations on waste rock slopes could facilitate forest trees recruitment by changing the undergrowth microclimatic conditions while limiting soil erosion. On one hand, fast-growing trees like hybrid poplar develop an extensive root system which rapidly colonizes the available soil volume (Douglas et al., 2010; Wilkinson, 1999), as well as a canopy which protects the soil from rain drop impacts. On the other hand, the facilitation theoretical model (Connell and Slatyer, 1977) tells us that pioneer tree species like poplar, which are able to colonize disturbed sites, prepare the environment for tree species which come later in forest succession.

Thus fast-growing poplars may be used to quickly stabilize the soil against erosion while facilitating forest recolonization. However, the plantation design that should be used to achieve both objectives remains unknown. To overcome this knowledge gap, a hybrid poplar plantation was established in 2013 on waste rock slopes of the Canadian Malartic gold mine in Quebec. The influence of plantation design in terms of tree spacing and combination with hydroseeding of herbaceous species was evaluated on: 1) soil erosion, vegetation and litter cover, and root development in superficial soil, and 2)

microenvironmental conditions controlling seed germination, seedling development and survival of forest trees.

Experimental setting

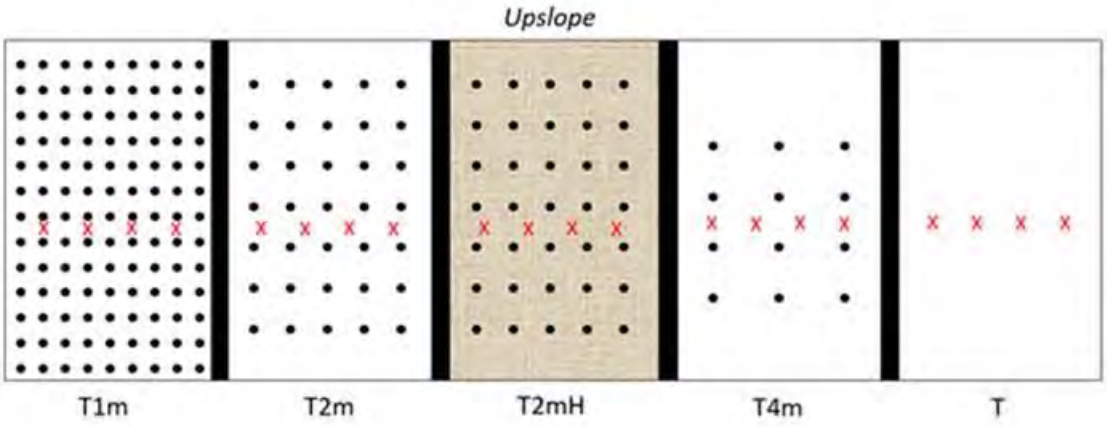

Figure 1. Representation of one repetition block (among three) of the experimental plantation established in 2013: black dot represent trees. Five treatments were tested: three tree spacing (T1m: 1x1m, T2m: 2x2m, T4m: 4x4m), hydroseeding of agronomic herbaceous species with planted trees at 2x2m (T2mH), or soil cover without revegetation (T: no trees, no hydroseeding).

Results

Along the three years after planting, no treatment effect was found on planted tree survival, which remained close to 100%. Soil loss was the lowest in plots with planted trees at 2x2m and hydroseeding (T2mH) while it was the greatest in control plots without planted trees and hydroseeding (T, Figure 2). Plots planted with hybrid poplars without hydroseeding showed intermediate soil losses. Undergrowth cover and herbaceous root length density were greater in hydroseeded plots compared to other plots, but the difference attenuated with time thanks to natural vegetation colonization of plots without hydroseeding. Tree canopy cover and root length density were greater in high density plantations (1x1m) compared to the other spacing treatments (2x2, and 4x4m).

Plots with intermediate tree density (2x2m) showed the greatest number of naturally colonizing seedlings of poplars and willows. Germination rates of tree species coming later in the boreal forest succession, i.e. *Picea glauca* [Moench] Voss and *Abies balsamea* [L.] Miller, increased in 1x1m planted plots compared to other treatments concomitantly to an increase in the volumetric water content of superficial soil with planting density (Figure 3). Finally, the hydroseeded treatment provided the lowest abundance of pioneer trees and balsam fir seedlings.

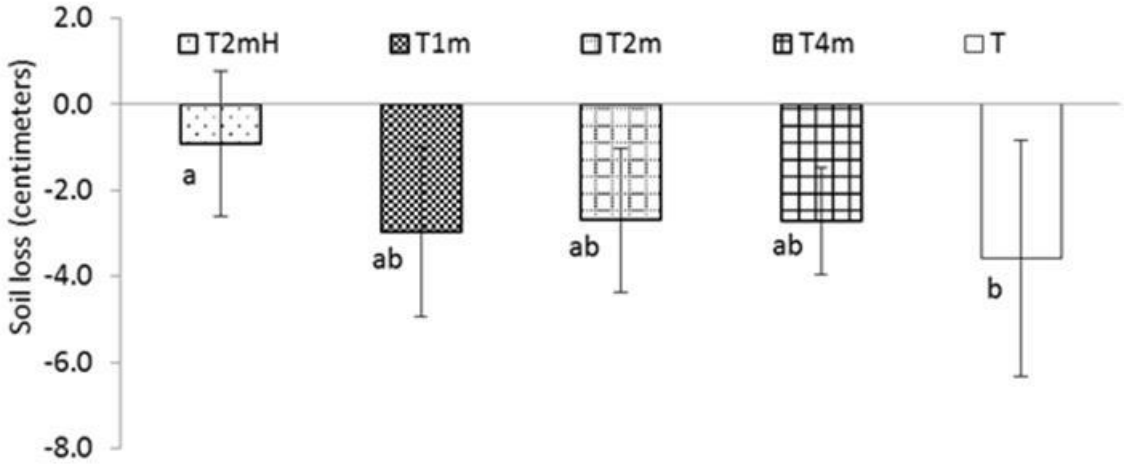

Figure 2. Mean soil loss (cm) during spring snow melt in the two-year-old plantation (2014) among the five tested treatments: three tree spacing (T1m: 1x1m, T2m: 2x2m, T4m: 4x4m), hydroseeding of agronomic herbaceous species with planted trees at 2x2m (T2mH), or control with soil cover but no revegetation (T). (N=12). Bars denote SE. Means that do not differ at the 0.05 level are noted with the same letter (a < b)

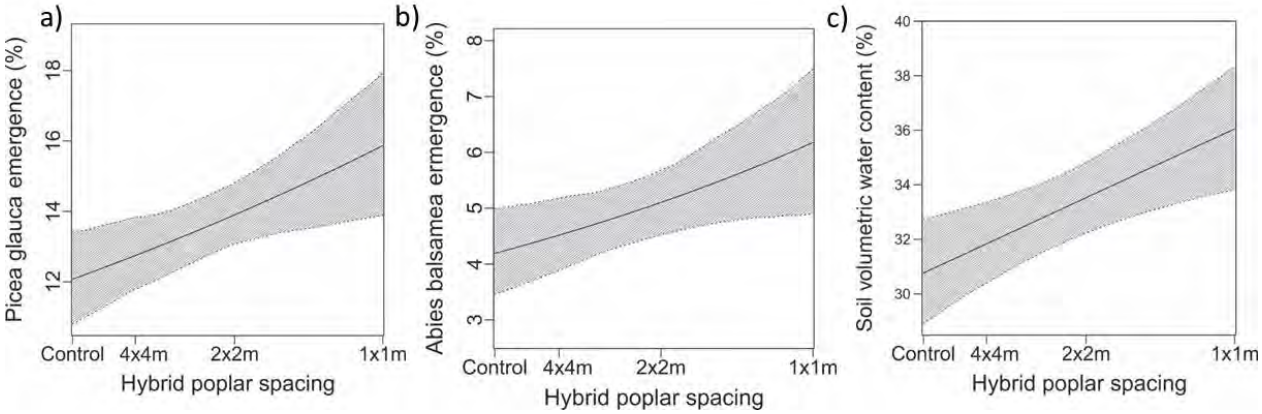

Figure 3. Seedling emergence rates of (a) *Picea glauca* and (b) *Abies balsamea* in relation to hybrid poplar spacing after spring seeding in the 3-year-old plantation (2015), varying in accordance with the increase in (c) soil volumetric water contents along the same gradient. Results presented in (a) and (b) summarize total summer emergence, whereas results in (c) are based on the average value measured from mid-May to mid-June, when the largest proportion of emergences were recorded for both species. Fitted values and 90% confidence intervals were estimated by Monte Carlo simulations from generalized and linear mixed-effects models.

Conclusion

At the short term, hydroseeding of herbaceous species remained the most efficient method to limit soil erosion in waste rock slopes thanks to a greater aerial cover and root development of the undergrowth vegetation as soon as the first year after planting. On

the other hand, planted tree growth, as well as the success of forest tree recruitment, were decreased in plots hydroseeded with herbaceous species.

Fast-growing plantations also decreased soil erosion compared to control plots without trees and without hydroseeding. Their positive effect improved the second year after planting according to tree growth and undergrowth vegetation development.

Finally, the treatment with high planting density (1x1m) presented greater soil water volumetric content the third year after planting, which was favorable to *Picea glauca* and *Abies balsamea* recruitment compared to other treatments. Moreover, the same treatment with high planting density could better protect the soil from erosion from the third year after planting onwards because it presented a greater tree canopy cover and a greater root development of trees compared to lower planting densities.

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