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The effect of cover crop species on growth and yield response of tree seedlings to fertiliser and soil moisture on reclaimed sites

A.A Kimaro *University of Saskatchewan, Canada*

K.F. Salifu *Suncor Energy Inc., Canada*

Abstract

*Several grass species are being screened to identify appropriate cover crops for stabilising recently reclaimed oil sands sites and for nursing newly planted tree seedlings on these sites. Besides soil erosion control, cover crops can influence the establishment success of tree seedlings by regulating the impacts of nutrients, moisture, and light on early survival and growth. However, interspecific interactions determining the net effects of these resources on tree seedling establishment in the Oil sands region are poorly understood. This study evaluated growth and yield responses of trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) seedlings to fertiliser, soil moisture, and cover crop species using the bioassay factorial experiment. The objective was to characterise the effects of interspecific interactions on growth of tree seedlings. Barley (*Hordeum vulgare*) and oats (*Avena sativa*) were used as test crops because these herbaceous species are being recommended for oil sands reclamation operations. Significant height and root collar diameter (RCD) growth increments of tree seedlings after fertilisation were attributed to differential growth rates between tree species. In contrast, soil moisture stimulated height, shoot and root biomass yields of tree seedlings. Cover crops species largely controlled growth and yield responses of tree seedlings to fertiliser and soil moisture. Even with fertilisation, RCD increment and shoot biomass yield were reduced by 26–51% and 36–68%, respectively, relative to the no grass treatment (grass control). These effects increased with increasing fertiliser and moisture levels, indicating enhanced access to growth resources by tree seedlings after alleviating interspecific competition. Comparatively the suppressive effect of barley was higher than that of oats probably due to a combination of vigorous growth and possible allelopathic effects. Apparently, weed competition may adversely affect early growth and yield of tree seedlings on reclaimed oil sands sites by inducing or augmenting the effects of nutrient limitation and moisture stress. However, revisiting fertiliser recommendations to account for nutrient uptake by the competing vegetation may be the appropriate approach for enhancing tree seedling growth in the oil sands region because cover crops are planted for stabilising recently reclaimed sites. This approach, however, need to consider the observed species-specific response to weed competition.*

1 Introduction

A key component of successful land reclamation is re-vegetation to stabilise soils and restore ecosystems functions, especially nutrient cycling. Rapid reforestation of reclaimed sites largely depends on the establishment success of planted tree seedlings. These sites however, are generally difficult to regenerate successfully since early survival and growth of tree seedlings are often limited by several factors, including low soil fertility, soil compaction, and competition from weed (Moffat, 2004; Casselman et al., 2006). Weed competition may adversely affect outplanting success of tree seedlings on newly reclaimed sites by augmenting the impacts of moisture and nutrient stress. Despite these deterrents, studies suggest that native vegetation with productivity and ecosystem processes similar to those of undisturbed conditions can be established (Rodrigue and Burger, 2004; Rowland et al., 2009) when appropriate silvicultural treatments for mined sites are applied (Moffat, 2004).

Competing vegetation in mined sites are a result of ground cover, especially grasses, sown to control soil erosion (Renault et al., 2003). Barley (*Hordeum vulgare*) and oats (*Avena sativa*) are some of the ground cover crops that are being tested in combination with native grass species to identify appropriate cover crops for stabilising recently reclaimed oil sands sites and for protecting planted tree seedlings (Renault et al., 2003). Although barley is currently recommended for field operations, mechanisms of facilitative and competitive interactions of barley and oats with trees are poorly understood. In particular, it is not well known how these cover crops interact with fertiliser to improve or adversely affects early survival and growth of tree seedlings.

Conventional approaches for fertiliser recommendation are based on matching application rates with the actual plant growth and nutrient uptake (Salifu and Jacobs, 2006) or modelled plant growth and uptake from soil nutrient analysis (Qian and Schoenau, 2002) to identify the rate that optimises plant growth. To the best of our knowledge, such kind of studies are lacking for the oil sands region. In addition to evaluating tree-cover crop interactions this study was established to refine fertiliser prescriptions for the successful establishment of tree seedlings in order to minimise operation and environmental costs associated with high inputs of mineral fertilisers and/or organic amendments. Specific objectives were to determine: 1) the fertiliser rate that optimises early survival, growth (height and diameter) and nutrition of tree seedlings and assess whether fertiliser application is desirable and beneficial for tree seedling establishment, 2) how cover crops (barley and oats) interacts with the nitrogen phosphorus and potassium (NPK) fertiliser to influence (improve or hamper) early survival and growth of tree seedlings, and 3) if soil moisture may modify such interactions. This paper presents preliminary results of the bioassay greenhouse trial which evaluated tree seedling-cover crops interactions in a bioassay experiment. Results will be useful in providing guidance for refining current fertiliser recommendations to optimise early survival and growth of tree seedlings while accounting for nutrient competition by cover crops.

2 Materials and methods

2.1 Experimental design, treatments and management

This study adopted a 2 × 2 × 3 × 3 factorial experiment laid out in a randomised complete block design (RCBD) with four replicates in a greenhouse. Factors tested include tree species (Trembling aspen and white spruce), soil moisture (with and without moisture stress), the NPK fertiliser at 0, 700 (half rate) and 1,400 kg ha^{-1} (full rate); and grass species (control, barley, oats). Barley and oats were used as test crops because these herbaceous species are being recommended oil sands reclamation operations. Fertiliser rates are based on the Suncor's field application rate (300 kg/ha). Water soluble fertiliser 20–20–20; containing 20, 9 and 17% of N, P and K, respectively, plus microelements was used for this study. The fertiliser mixture was applied in solution as three equal splits on week 1, 4, and 8 after planting to enhance nutrient availability throughout the experimental period. Soil moisture was maintained at 80% and 40% of field capacity for the no water stress and water stress treatments, respectively. Equal amount of peat-mineral mix cover soils used for Suncor's reclamation operations was filled in each pot. Then moisture content at container capacity was determined prior to planting seedlings by watering the pots with distilled water and draining the pots for 24 hours and the process repeated for three days to achieve full saturation (Salifu and Timmer, 2003). On each day, containers were weighed and soil samples collected for gravimetric moisture content determination at 105°C. Then the volume of water at field capacity was calculated and used as a basis for determining the volume of water required to maintain soil moisture at full and 40% container capacity. Moisture stress was induced by withholding irrigation until soil water content decline to 40% field capacity. This treatment was initiated two weeks after establishing the experiment to allow roots of tree seedlings and grass to develop. Thereafter, a hand held Time Domain Reflectrometry (TDR) meter (TDR 100) was used to monitor volumetric soil moisture content in pots at the predetermined moisture levels (40% and 80%) throughout the experimental period. Seedlings and grass species were grown for 16 weeks corresponding to one growing season.

Tree seedlings were measured for height and root collar diameter (RCD) at two week intervals using a tape and digital vernier caliper. To account for the variation of tree seedling size, initial measurements were taken immediately after planting and used for calculating height and RCD growth increments. At the termination of the experiment, all tree seedlings and grass plants were harvested and portioned into shoot and root biomass components for over-dry weight determination at 70°C. Prior to oven drying root samples were washed under 0.5 mm sieve to remove soil materials.

2.2 Experimental design, treatments and management

Data for growth (height and RCD increments) and biomass yield (shoot, root and total) of tree seedlings after 16 weeks were subjected to analysis of variance (ANOVA) using the mixed model procedure in the statistical analysis system (SAS Institute, 2000). Fertiliser rate, soil moisture, tree and grass species, and interactions of these factors were fixed effects variables while block and block-by-treatment interaction were random effects variables in the model. Following ANOVA significant treatments were compared using to Tukey's studentised range test at 5% probability levels.

3 Results and discussion

3.1 Height and diameter growth

The interactions between fertiliser and soil moisture significantly increased height and RCD growth of tree seedlings (Figure 1). With and without fertilisation, height ($p = 0.0009$) and RCD ($p = 0.0253$) growth of trembling aspen seedlings were significantly higher than corresponding growth of white spruce seedlings (Figures 1a and 1b). Except for the height increment in trembling aspen, there was no significant fertiliser effect on seedling growth, suggesting that peat mineral mixture and/or other organic amendments used for reclamation operations (McMillan et al., 2007; Rowland et al., 2009) may provide sufficient soil nutrients to support growth and establishment of tree seedlings. Apparently, significant fertiliser-by-species interactions on height and RCD increments largely reflect rapid initial growth of trembling aspen seedlings because white spruce seedlings showed little response to fertilisation over the entire experimental period (Figures 1a and 1b). Height and RCD growth of trembling aspen seedlings increased by 18–29 cm and 1.7–3.2 cm, respectively and by 2.8–3.1 cm and 1.7–3.2 cm for white spruce seedlings. This fast growth of trembling aspen may enhance competitiveness of tree seedlings for light in the field since planted seedlings can be overtopped by cover crops, especially barley. This is critical for early survival and growth of tree seedlings under field conditions because light competition by barley has been attributed to suppression of weed growth (Bowman et al., 1998; Kremer and Ben-Hammouda, 2009). Soil moisture stress also reduced growth of tree seedlings, especially height increments of trembling aspen (Figures 1c and 1d). On the other hand, height and RCD growth of white spruce seedlings were generally little affected by fertiliser inputs and soil moisture availability (Figures 1a to 1d), possibly reflecting low resource demand due to slow initial growth rate.

Apparently, interspecific competition modified seedling response to fertiliser and soil moisture (Figure 2). With and without fertiliser addition, barley and oats suppressed height growth of tree seedlings by 50% (Figures 2a and 2b). The effects were significant for RCD at half and full rates, implying that suppressive effects of cover crops were enhanced by fertilisation. This could be a result of vigorous growth after fertilisation, which may lead to increased demand for nutrients and/or moisture. Cover crop species reduced increase in both height ($p = 0.0007$) and RCD ($p = 0.0018$) of tree seedlings at 40% and 80% field capacity (Figures 2c and 2d). This result would indicate that competition for soil moisture was probably more severe than competition for soil nutrients.

The overall effects of grass competition for nutrients and soil moisture were more pronounced in trembling aspen seedlings than for white spruce seedlings (Figures 2e and 2f). Both RCD ($p < 0.001$) and height ($p < 0.001$) increase of trembling aspen seedlings in mixture were reduced by 54% and 63% in barley treatments compared to 47% and 46% in oats treatments. These results indicate that trembling aspen seedlings were more sensitive to interspecific competition and barley competed more strongly for growth resources than oats. Rapid growth and tolerance to a wide range of soil and environmental conditions are key attributes associated with superior competition of barley for soil nutrients and moisture in mixture (Bowman et al., 1998; Kremer and Ben-Hammouda, 2009). Allelochemicals, mainly from root exudates and residue decomposition of barley, has also been noted to reduce plant growth in mixed and rotational cropping systems (Kremer and Ben-Hammouda, 2009). Similar responses of tree seedlings to barley and oats treatments, however, suggest that barley allelopathic effects were possibly minimal. This could be attributed to less vigorous growth of cover crops in pots and the lack of plant residue to decomposition because the experiment was terminated soon after physiological maturity of grass species.

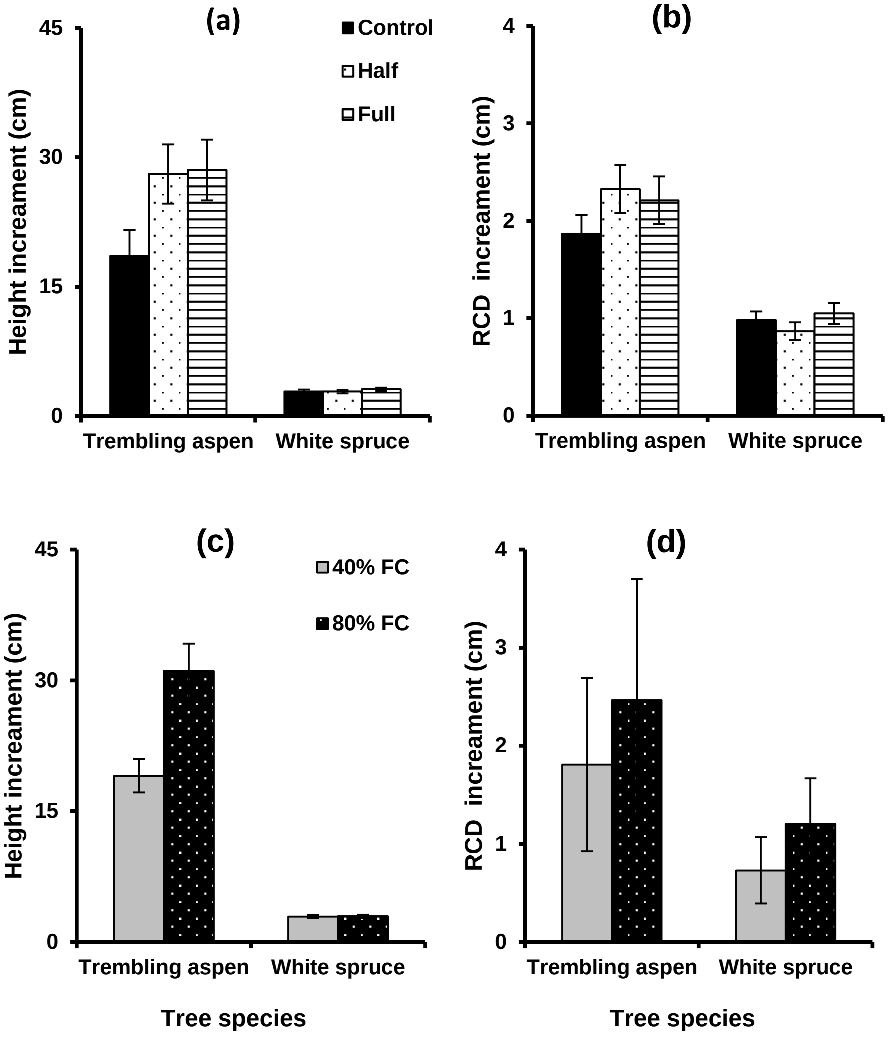

Figure 1 Height and root collar diameter (RCD) growth response of tree seedlings to NPK fertiliser (a–b) and soil moisture at field capacity (FC) (c–d) after 16 week growth in a greenhouse bioassay experiment. Application rates of the 20–20–20 NPK fertiliser were: control = no fertiliser, half = 350 kg ha^{-1} and full = 1,400 kg ha^{-1}. Vertical bars indicate standard error of means (n = 4)

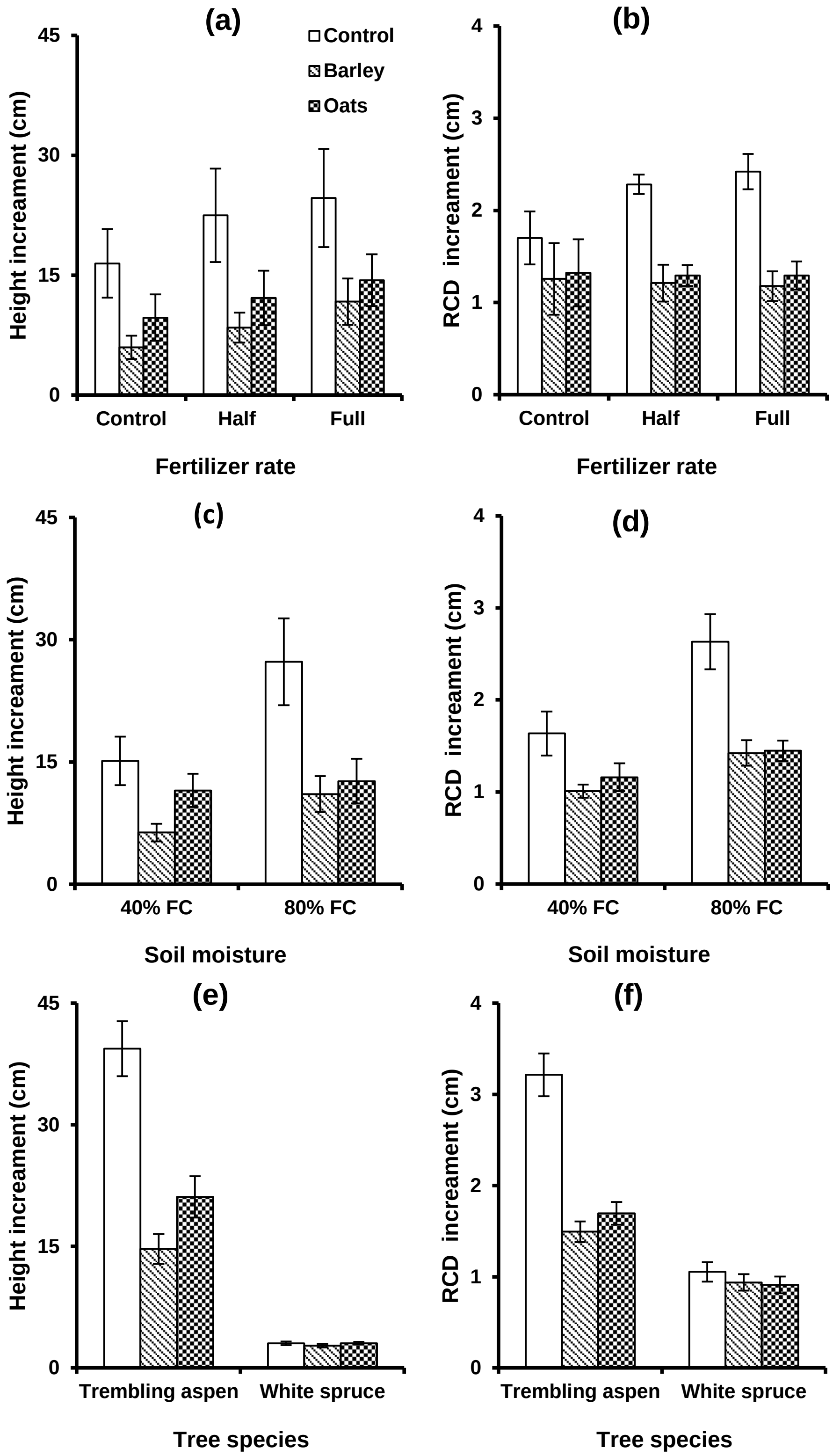

Figure 2 **Height and root collar diameter (RCD) increments of tree seedlings for the interactions between cover crops and fertiliser (a–b) or soil moisture at field capacity (FC) (b–c) or tree species (e–f) after 16 week growth in a greenhouse bioassay experiment. Application rates of the 20–20–20 NPK fertiliser were: control = no fertiliser, half = 350 kg ha^{-1} and full = 1,400 kg ha^{-1}. Vertical bars indicate standard error of means (n = 4)**

3.2 Biomass yield of tree seedlings

Fertiliser application did not significantly increase shoot and root biomass yields of trembling aspen and white spruce seedlings (Figures 3a and 3b). Despite the rapid growth of trembling aspen seedlings (Figures 1a and 1b), biomass yields of these species were also similar. In contrast, trembling aspen seedlings recorded a 30% decrease in root biomass ($p < 0.0123$) and a 50% decrease in shoot biomass ($p < 0.0001$) at 40% field capacity compared to 80% field capacity (Figures 3b and 3d). These yield reductions corroborate earlier results that soil moisture was probably the main factor driving seedlings growth (Figures 1c and 1d).

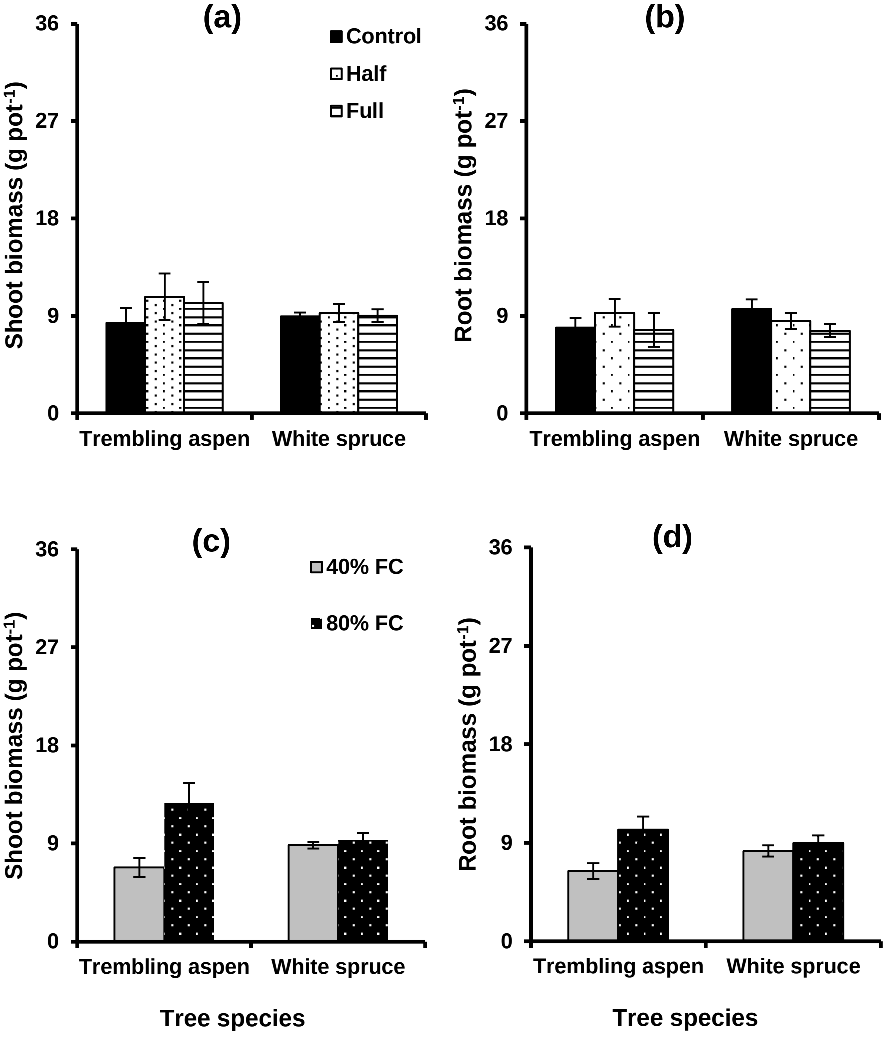

Figure 3 **Shoot and root biomass yield response of tree seedlings to NPK fertiliser (a–b) and soil moisture (c–d) after 16 week growth in a greenhouse bioassay experiment. Application rates of the 20–20–20 NPK fertiliser were: control = no fertiliser, half = 350 kg ha^{-1} and full = 1,400 kg ha^{-1}. Vertical bars indicate standard error of means (n = 4)**

Fertilisation doubled shoot biomass ($p = 0.0191$) and root biomass ($p = 0.0101$) yields of tree seedlings in the no grass treatment relative to barley and oats treatments (Figures 4a and 4b). Similar results were also noted for shoot and root biomass at 40% and 80% field capacity (Figures 4c and 4d). As mentioned earlier, the increase indicates that cover crops suppressed yield response of tree seedlings to fertiliser and soil moisture. This effect was more pronounced for trembling aspen seedlings compared to white spruce seedlings (Figures 4e and 4f), reflecting high sensitivity to competition by the former.

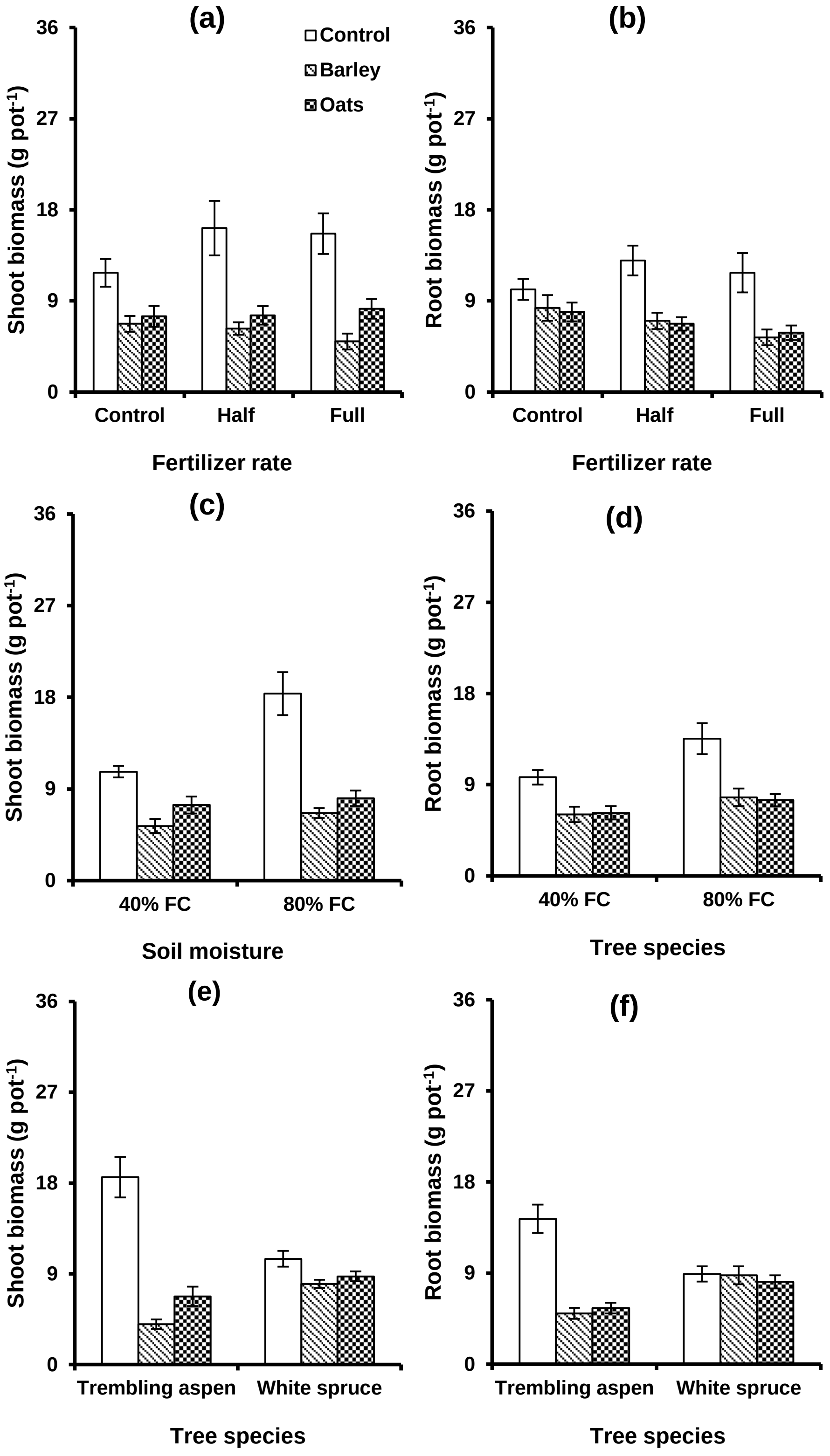

Figure 4 Shoot and root biomass yields of tree seedlings for the interactions between cover crops and fertiliser (a–b) or soil moisture at field capacity (FC) (b–c) or tree species (e–f) after 16 week growth in a greenhouse bioassay experiment. Application rates of the 20–20–20 NPK fertiliser were: control = no fertiliser, half = 350 kg ha^{-1} and full = 1,400 kg ha^{-1}. Vertical bars indicate standard error of means (n = 4)

3.3 Biomass yield of cover crops

Biomass yield of barley mixed with tree seedlings was higher than that of oats (Table 1), possibly due to rapid growth and high competitive effects of this species (Kremer and Ben-Hammounda, 2009). Overall, fertilisation doubled biomass yield of grass biomass relative to unfertilised control. Yields of cover crops were also increased by 50% at 80% field capacity relative to the moisture stress condition. These results indicate that fertiliser addition and sufficient moisture level are necessary for rapid establishment of cover crops in recently reclaimed sites. Trembling aspen slightly reduced yields of grass species by 14% compared to white spruce, possibly due to high resource demand associated with the rapid initial growth of this species.

Table 1 Biomass yield of grass species after 16 week growth in the greenhouse

	Biomass Yield (g/pot)		
	Shoot	**Root**	**Total**
Fertiliser			
Control	17.63c*	1.13c	18.76c
Half	31.12b	2.36b	33.48b
Full	36.33a	3.31a	39.64a
MSD	2.98	0.9407	3.3216
Pr>F	<0.0001	<.0001	<0.0001
Grass species			
Barley	31.13a	3.13a	34.27a
Oats	25.58b	1.40b	26.98b
MSD	1.94	0.6125	2.1628
Pr>F	<0.0001	<.0001	<0.0001
Tree species			
Trembling aspen	26.56b	1.99b	28.54b
White spruce	30.16a	2.54a	32.71a
MSD	1.94	0.6125	2.1628
Pr>F	0.0081	0.0143	0.0037
Soil moisture			
40% FC	22.81b	1.54b	24.35b
80% FC	33.91a	3.00a	36.90a
MSD	1.94	0.6125	2.1628
Pr>F	<0.0001	<.0001	<0.0001

Mean of four replicates (n = 4). Means followed by the same letter are not statistically significant at $p<0.05$. MSD = Minimum significant difference.

Unlike tree seedlings, biomass yields of barley and oats were not affected by treatment interactions ($p<0.05$), suggesting that these cover crops accessed sufficient amount of growth resources, especially at the vegetative growth periods, because of initial faster growth rates compared to the tree component. Hence reduced growth and yields of tree seedlings in mixture (Figures 2 and 4) would also suggest that nutrients contents in recently reclaimed sites may not be sufficient to optimise growth and yields of both grass and tree components. Tested cover crops are annuals, which imply that interspecific interactions noted here may be short-lived and could be minimal in subsequent years. However, field studies are needed to verify this expectation because allelochemicals from barley residues has been reported to influence crops grown in soils previously planted with barley (Gubbels et al., 1989; Kremer and Ben-Hammounda, 2009).

Overall this study suggests that weed competition may adversely affect early growth and yield of tree seedling on reclaimed oil sands sites by augmenting the effects of moisture stress and nutrient limitation (Figures 2 and 4). However, controlling weeds and fertiliser addition can improve the establishment success of tree seedlings in mined sites (Moffat, 2004; Casselman et al., 2006). Therefore, revisiting fertiliser recommendations to account for nutrient uptake by the competing vegetation may be necessary for enhancing seedling growth in the oil sands region because cover crops are needed for stabilising recently reclaimed sites. This approach, however, need to consider species-specific response to weed competition (the sensitivity of tree species to interspecific competition), noted in Figures 2a and 2b and Figures 4e and 4f.

4 Conclusion

Both trembling aspen and white spruce seedlings responded poorly to fertiliser additions. Despite rapid initial growth rates of trembling aspen seedlings, shoot and root biomass yields after 16 week growth period did not differ between these tree species, suggesting that fertiliser did not influence growth and yields of tree seedlings. In contrast, soil moisture stimulated height, shoot and root biomass yields of tree seedlings, implying that availability of soil moisture was probably the most limiting factor for growth. Grass species competition largely determined growth and yield responses of tree seedlings to fertiliser inputs and soil moisture availability. Even with fertilisation, RCD growth and shoot biomass yield of tree seedlings were reduced by 45–50% and 50–65%, relative to the no grass treatment (grass control). The effects increased with increasing fertiliser application rates because of higher uptake in the grass control treatment. Similar effects were also found for soil moisture both with (40% FC) and without (80% FC) moisture stress. Apparently, weed competition may adversely affect early growth and yield of tree seedlings on reclaimed oil sands sites by inducing or augmenting the effects of nutrient limitation and moisture stress. Controlling weeds and fertiliser addition can help to improve establishment success of tree seedlings. However, revising fertiliser recommendations to account for nutrient uptake by the competing vegetation may be the appropriate approach for enhancing seedling growth in the oil sands region because cover crops are planted for controlling soil erosion on recently reclaimed sites. This approach, however, need to consider the observed species-specific response to weed competition.

Comparatively the suppressive effect of barley was higher than that of oats probably due to a combination of vigorous growth and possible allelopathic effects. A follow up study is recommended to examine if these interactions will persistent in subsequent years and recommend fertiliser rate for optimising growth and yield of both grass and tree seedlings. Seedlings of trembling aspen were more sensitive to interspecific competition than white spruce seedlings. However, stimulated height and RCD growth after fertilisation can enhance competitiveness of trembling aspen seedlings to aboveground resources, especially light. This is critical to early survival under field conditions because tree seedlings are often overtopped by established cover crops planted to stabilise soils in new reclaimed sites.

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