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Effect of soil mounding and mechanical weed control on hybrid poplar early growth and vole damage [1]

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Abstract: This study compared growth of hybrid poplar in relation to soil mounding and mechanical weed control on a former agricultural site under boreal climate in order to assess optimal management scenarios. Height and basal diameter growth of 2 clones (*Populus maximowiczii* × *P. balsamifera* [915319] and *P.* × *euramericana* × *P. maximowiczii* [916401]) were evaluated after 3 growing seasons in 2 mounding (mounded, unmounded) and 4 weed control treatments (0: no weed control; 1, 2, and 3: 1, 2, or 3 passes of mechanical weed control). Net photosynthesis, stomatal conductance, soil temperature, and percent cover and height of competing vegetation were measured to explain the effects of soil mounding and weed control on tree growth. Two passes of weed control increased growth of trees by 23% in basal diameter and 12% in height, while mounding had no effect on growth. Both mounding and weed control reduced the cover of weedy vegetation, which was negatively correlated with growth of clone 915319. Mounding did not increase mean soil temperatures in spring and even reduced them in the fall, while weed control had no effect on soil temperature. Finally, mounding significantly reduced the frequency and severity of damage (girdling) caused by voles during 2005–2006, especially for the plots that were not weeded.
Keywords: hybrid poplar, mechanical weed control, *Populus* spp., site preparation, soil mounding.

Résumé : Cette étude a examiné la croissance du peuplier hybride en lien avec la formation de monticules de sol et le contrôle mécanique des mauvaises herbes sur un ancien site agricole en climat boréal dans le but d'évaluer des scénarios d'aménagement optimaux. La hauteur et la croissance du diamètre basal de 2 clones (*Populus maximowiczii* × *P. balsamifera* [915319] et *P. euramericana* × *P. maximowiczii* [916401]) ont été évaluées après 3 saisons de croissance dans 2 traitements en lien avec des monticules de sol (avec et sans monticules) et 4 traitements liés au contrôle des mauvaises herbes (0 : aucun contrôle; 1, 2 et 3 : 1, 2 ou 3 répétitions d'un contrôle mécanique). La photosynthèse nette, la conductance stomatique, la température du sol, le pourcentage de couverture et la hauteur de la végétation compétitrice ont été mesurés pour expliquer les effets des monticules de sol et du contrôle des mauvaises herbes sur la croissance des arbres. Deux contrôles des mauvaises herbes ont causé une augmentation de 23 % de la croissance du diamètre basal et de 12 % de la hauteur des arbres, tandis que les monticules de sol n'avaient aucun effet sur la croissance. La formation de monticules de sol et le contrôle des mauvaises herbes ont tous les 2 causé une réduction de la couverture des mauvaises herbes qui était corrélée négativement avec la croissance du clone 915319. La formation de monticules de sol n'a pas causé d'augmentation des températures moyennes du sol au printemps et les a même diminuées en automne, tandis que le contrôle des mauvaises herbes n'avait aucun effet sur la température du sol. Finalement, la formation de monticules de sol a réduit significativement la fréquence et la sévérité des dommages (annelage) causés par les campagnols en 2005–2006 surtout dans les parcelles qui n'avaient pas été entretenues.
Mots-clés : contrôle mécanique des mauvaises herbes, monticules, peuplier hybride, *Populus* spp., préparation du site.

Nomenclature: Reich, 1981; Marie-Victorin, 1995.

Introduction

Timber exploitation from native forests in Canada is increasingly subjected to limitations as the proportion of pristine forests around the world continues to fall (Bradshaw, Warkentin & Sodhi, 2009). Using wood from intensively managed plantations is thus becoming an unavoidable means for the forest industry to sustain wood biomass production on reduced land areas. Plantations of hybrid poplars (*Populus* spp.) are especially interesting (Gordon, 2001), due to their much faster growth rates compared to native species (Dickmann *et al.*, 2001), even in northern regions (Farmer *et al.*, 1991; Pothier & Savard, 1998). Although great progress has been achieved in Canada in the development of fast-growing and cold-hardy hybrid poplar clones (Zsuffa, 1969; Ménétrier, 2008), silvicultural expertise still needs to be developed, as intensive management is essential if the full growth potential of these plantations is to be realized (Ceulemans & Deraedt, 1999).

Preferably, plantations should be established in areas where natural regeneration is lacking after harvesting, since silvicultural interventions would already be required to meet regeneration standards and maximize wood production on the land base. In northeastern Canada, the agricultural depression that has occurred over the past 25 y in the Clay Belt forest region (Rowe, 1972) has left considerable amounts of abandoned farmland, most of which is suitable

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for establishing fast-growing plantations. In the Abitibi-Temiscamingue region (northwestern Quebec) alone, nearly half of the agricultural enterprises and more than 15% of cultivated lands (34 000 ha) have been abandoned since 1981 (Rompré & Carrier, 1997; L'Observatoire de l'Abitibi-Témiscamingue, Online). These fallow lands are easily converted to plantations and provide great afforestation opportunities to offset greenhouse gas emissions (Graham, 2003; Yemshanov & McKenney, 2008).

Hybrid poplars grow best on loamy-type soils (Dickmann *et al.*, 2001), whereas the soils of the Clay Belt region are mostly fine-textured heavy clays, forming a compact matrix with little aeration for tree roots (Brais, 2001). This soil type also tends to thaw slowly in the spring, keeping soil temperatures low and limiting spring root development (Landhäusser & Lieffers, 1998; Pregitzer *et al.*, 2000). Although rich in nutrients (Rompré & Carrier, 1997), these soils are often covered with a thick grass layer that strongly competes with planted trees for nutrients and water (Nambiar & Sands, 1993; Coll *et al.*, 2007; Pinno & Bélanger, 2009). Weedy grass vegetation, with its dense network of rhizomes, forms an insulating layer that keeps sun rays from warming the mineral soil, limiting tree growth (Cogliastro *et al.*, 1990; Hogg & Lieffers, 1991). These factors, coupled with a short growing season, require that modified silvicultural methods be developed for plantations to reach their desired high levels of productivity.

Site preparation before the establishment of poplar plantations in clay soils usually consists of deep (>30 cm) ploughing and disking to break up, loosen, and aerate soil particles (Guillemette & DesRochers, 2008; DesRochers & Tremblay, 2009). Mounding can also be used to increase spring soil temperatures by increasing contact area between the soil and air (Örlander, Gemme & Hunt, 1990; Sutton, 1993; DesRochers, Thomas & Butson, 2004), and to alleviate water-logging problems during the spring melt (Berguson & Adams, 1989; Sutton, 1993). These techniques not only improve soil structure (Sutton, 1993) and increase soil temperatures, they can also slow down weed re-invasion of the plantation site (Löf & Birkedal, 2009). Weeds are especially challenging in Quebec since the use of herbicides is prohibited in plantations and most mechanical weed control methods have proven to be inefficient unless weeds have been completely removed (Thomas, Comeau & Brown, 2000; Coll *et al.*, 2007). Although weed control is usually achieved by chemical applications in most places around the world, mechanical weed control, by aerating and loosening the soil surface and incorporating organic matter, brings added benefits compared to herbicide applications alone (Baker & Blackmon, 1978; van den Driessche, 1999).

The objectives of this study were to evaluate the effects of soil mounding and mechanical weed control on the growth of hybrid poplars planted on heavy clay soils of the Clay Belt forest region. We hypothesized that soil mounding and a greater number of weed control passes would increase growth rates of trees by increasing spring average soil temperatures (DesRochers, Thomas & Butson, 2004) and decreasing competition by weeds. Unexpected heavy vole damage during the 2005–2006 winter also prompted us to assess the occurence of vole damage in relation to soil mounding and weed control frequency. Although widely used for agricultural crops, use of soil mounding and mechanical weed control for the culture of hybrid poplars is relatively new (Dickmann *et al.*, 2001), and expertise needs to be developed, especially for regions where the nature of the soil and the climate are particularly challenging.

Methods

Study area

A hybrid poplar plantation was established in 2004 in the Abitibi-Témiscamingue region (northwestern Quebec), in the western balsam fir–paper birch bioclimatic domain (Grondin, 1996), near the municipality of Preissac (48°37'N, 78°28'W). The site was an abandoned farmland covered with grasses only, located within the Quebec–Ontario Clay Belt created by deposits left by proglacial lakes Barlow and Ojibway (Vincent & Hardy, 1977), with typical heavy clay soil (Guillemette & DesRochers, 2008) and flat topography. The soil moisture regime is mesic, with a pH of 4.55 ($CaCl_2$). The organic matter, nitrogen (N), and clay contents of the soil are 1.08%, 0.06%, and 77%, respectively, measured at 15 cm depth.

Experimental design

The plantation site was ploughed in spring 2004 to a depth of 30 cm using a heavy V-shaped plough pulled by a bulldozer, followed by disking to approximately 20 cm depth. The experiment was set up as a split-block design where half of each block (replicate) was mounded, while the other half was left flat (main plot). Mounds were initially about 50 cm high and 80–90 cm wide. The main plot (mounded/unmounded) was divided (split-block) into 4 weed control frequencies (0, 1, 2, or 3 annual passes). Each of these 8 treatment combinations was then subdivided (split-plot) to randomly accommodate 2 hybrid poplar clones. This set-up was replicated 3 times (blocks). The planned weed control treatments were 0) no weed control; 1) a single pass done in the middle of the growing season (mid-July); 2) 1 pass in mid-July and 1 pass at the end of the growing season (end of August); and 3) 1 pass in mid-June, 1 in mid-July, and 1 at the end of August. However, only 1 pass was done in 2004, due to the slow return of weedy vegetation. The weed control schedule was completed as planned in 2005, while abundant rainfall in August and September of 2006 prevented us from doing the third weed control pass. Each replicate combination contained 648 trees, among which 160 trees from the centre of each experimental unit were measured (10 pseudo-replicates per treatment combination; n = 480). Weedy vegetation was mechanically removed by cultivating between the rows with farm disks and using a Weed Badger® (4020-SST, Weed Badger, Marion, North Dakota, USA) within the rows to a depth of approximately 10 cm. The combination of these 2 techniques enabled us to remove weedy vegetation from the entire surface of the plantation, while simultaneously aerating the soil surface.

Dormant, 1-y-old bareroot planting stock of 2 locally available hybrid poplar clones was used: clone 915319 (*Populus maximowiczii* × *balsamifera* [M×B]) and clone 916401 (*P.* × *euramericana* × *maximowiczii* [DN×M]). Trees were planted to a depth of 30 cm at 4 × 2.5 m spacing (1000 trees·ha^{-1}). Trees showed stem dieback shortly after planting (DesRochers & Tremblay, 2009) and were thus pruned to a height of approximately 50 cm to remove dead tops. Trees were spot-fertilized (Guillemette & DesRochers, 2008) in July 2005 with 100 g of 16N-32P-8K commercial blend of mineral fertilizer.

Height and basal diameter (5 cm above ground level) of trees were measured at planting and at the end of the 2006 growing season. Percent cover of weeds and their height were assessed monthly in 2006 within a 2.26-m-diameter circle around each tree, according to 6 cover classes: 0%; presence (1–13%); 25% (14–37%); 50% (38–63%); 75% (64–83%); and 100% (84–100%). Net photosynthesis (Pn) and stomatal conductance (Gs) were measured in July 2006 on 4 trees per treatment combination and replicate, with an infrared gas analyzer (CIRAS-2, PP Systems, Amesbury, Massachusetts, USA). The CIRAS-2 was coupled with a 25-mm-diameter broadleaf cuvette equipped with an LED light unit (PLC6-U, PP Systems). Air flow rate inside the cuvette was set at 350 mL·min^{-1} and CO_2 concentration at 350 ppm. Photosynthetically active radiation (PAR) was set at 1200 μmol·m^{-2}·s^{-1} and measurements were taken between 8:30 and 12:00. The order of measurements was randomized to reduce the time effect on net photosynthesis.

Hobo thermometers (H08-006-04, MicroDaq, Warner, New Hampshire, USA) were installed in 1 replicate of each soil mounding × weed control treatment. Each thermometer had 4 probes, of which 2 were installed at 10 cm depth, while the other 2 were installed at 20 cm depth (pseudo-replicates). The probes were buried at their corresponding soil depth early in the 2005 and 2006 growth seasons (May) and were removed after the first snow fall (end of October). Values from 2005 and 2006 were pooled to obtain mean monthly temperatures. Soil temperatures were recorded hourly, and monthly means were calculated.

Voles (probably *Microtus pennsylvanicus*) caused significant damage to the base of many trees during the 2005–2006 winter. The severity of this girdling was evaluated in relation to the proportion of stem circumference that had been gnawed on all trees at the site: trees were categorized as undamaged (<25% girdling), moderately damaged (25–75%), or severely damaged (>75%).

Statistical analyses

Height, basal diameter, net photosynthesis (Pn), stomatal conductance (Gs), percent cover and height of weedy vegetation, and rodent damage were analyzed using a split-block (Steel & Torrie, 1980) analysis of variance (GLM procedure, GLM procudure in SAS [version 9.3, Sas Institute Inc., Cary, NC, USA) with a chosen significance level of $P < 0.05$. Pearson's correlations were performed between percent cover and height of weeds and growth increment of trees for the period 2004–2006. Although dead trees were replaced in 2005, they were not considered in the analyses. Least squares means were compared using Fisher's Protected LSD in SAS.

Results

Trees reached an average height and basal diameter of 1.9 m and 3.4 cm, respectively, after 3 growing seasons. Survival was 92%, and those trees that did not survive mostly died soon after planting due to stock quality (stem dieback).

Increases in weed control passes generally increased growth of trees ($P = 0.03$ for basal diameter and $P = 0.048$ for height increment; Figure 1). However, there was no increase in basal diameter or height with a single pass compared to no weed control, and neither was there a benefit from the third pass done in 2005. Mounding had no effect on growth increments of trees ($P = 0.90$ for basal diameter and $P = 0.61$ for height), and the 2 clones had similar growth increments over the 3 growing seasons ($P > 0.05$).

There was a three-way interaction between mounding, weed control, and clone for net photosynthesis (Pn; $P = 0.02$), showing that weed control had no effect on Pn of trees on mounds, while it increased Pn for clone 915319 and decreased it for clone 916401 on flat terrain (Figure 2a). For clone 915319 only, stomatal conductance to water (Gs) increased with the number of weed control passes independently of mounding (Figure 2b).

The number of weed control passes significantly reduced percent cover and height of weeds (Figure 3). Mounding alone also reduced percent cover of weeds, except in the 2-weed-control-passes treatment, producing a significant interaction between mounding and weed control ($P < 0.001$; Figure 3a). Height of weeds, on the other

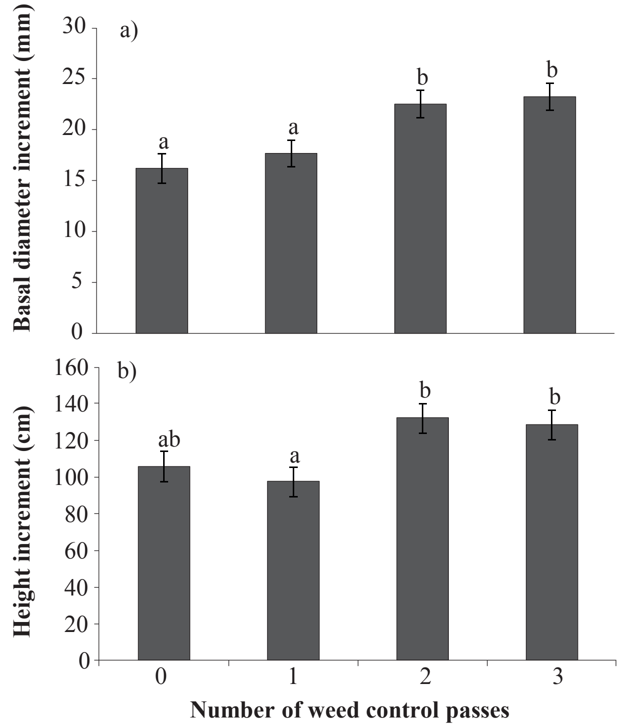

FIGURE 1. Mean basal diameter and height growth increments during the 2004–2006 growing seasons, for each weed control treatment (0, 1, 2, or 3 passes). Error bars are SE of the mean and bars with the same letter indicate that means were not significantly different at $P < 0.05$.

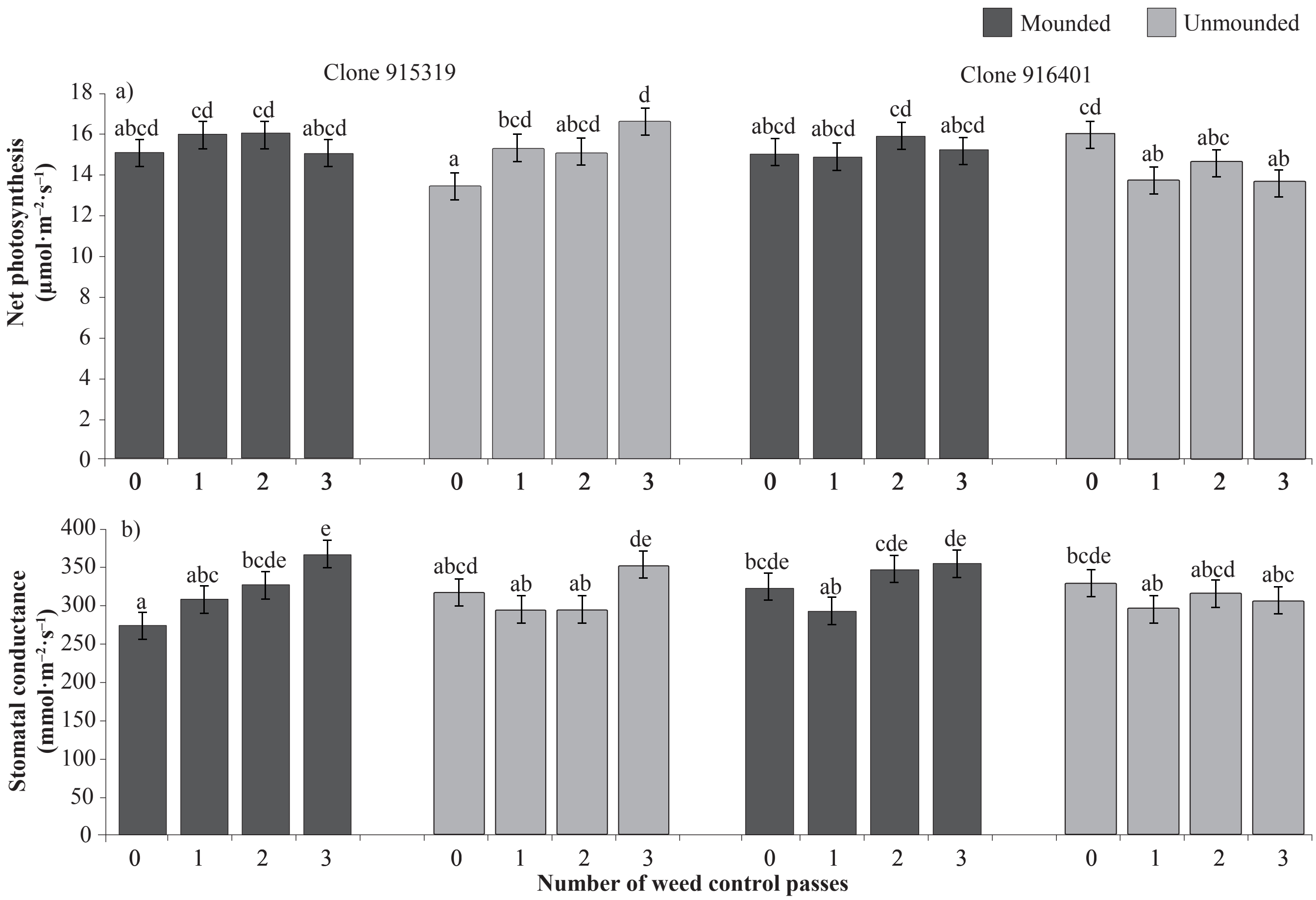

FIGURE 2. Mean a) net photosynthesis (Pn) and b) stomatal conductance (Gs) measured in 2006, showing the interaction between soil preparation treatment (mounded or unmounded), clone (915319 or 916401), and weed control (0, 1, 2, or 3 passes). Error bars are SE of the mean and bars with the same letter within a graph indicate that means were not significantly different at $P < 0.05$.

hand, was similar between mounded and unmounded terrain (Figure 3b). Height and basal diameter growth of clone 915319 were negatively correlated with percent cover and height of weedy vegetation (Table I). However, these correlations were weak, and no such correlation was found for clone 9163401 (Table I).

Soil temperatures were similar between the mounded and unmounded plots except in the fall, when the mounds were about 1 °C colder on average (Figure 4). Weed control did not affect soil temperatures (not shown).

Girdling at the base of trees by voles was observed in spring 2006, after snowmelt. Trees planted on mounds were less frequently girdled (31% of trees moderately to severely girdled) than trees on unmounded terrain (54% of trees moderately to severely girdled; $P < 0.001$; Figure 5). There was a higher proportion ($P = 0.04$) of severe attacks on unmounded (22%) compared to mounded terrain (7%; Figure 5). Three weed control passes significantly reduced girdling frequency (38%) compared to plots where no weed control was done (53%; Figure 6). The frequency of severe girdling was reduced by half when weedy vegetation was removed at least once (Figure 6). Few trees died from vole girdling (approx. 5%), as moderately browsed trees healed and entirely girdled trees re-sprouted from the base.

Discussion

The practice of soil mounding in poplar plantations is relatively recent (Dickmann *et al.*, 2001), although there is a long history of successfully using mounding in forest and agricultural plantations (Sutton, 1993). The benefits of mounding for hybrid poplar growth in this study were not convincing. In forest settings, beneficial effects of mounding on tree growth are often related to decreased weed competition and/or increased soil temperatures on mounds (DesRochers, Thomas & Butson, 2004; Löf, Rydberg & Bolte, 2006; Knapp, Wang & Walker, 2008; Löf & Birkedal, 2009). Mounds generally reduced the presence of weeds in our study (Figure 3), but soil temperatures on mounds remained similar to unmounded plots in the spring (Figure 4), while we had anticipated that mounds would warm up sooner than unmounded terrain. Perhaps the fact that the entire plantation site had been ploughed and disked enabled even the unmounded areas to reach good soil temperatures, unlike the totally unprepared sites in other studies (Heineman, Bedford & Sword, 1999; Nilsson & Örlander, 1999; DesRochers, Thomas & Butson, 2004; Löf & Birkendal, 2009; Bilodeau-Gauthier, Paré & Messier, 2011). Mounds can also induce water stress due to more rapid drainage and greater wind exposure (Sutton, 1993; Knapp, Wang & Walker, 2008; Löf & Birkedal, 2009). Our stomatal conductance (Gs) measurements, however, did not indicate greater drought stress on mounds (Figure 2b). The colder average soil temperatures measured in the fall (Figure 4) also do not support the use of mounding in these types of conditions. Warmer soil temperatures are beneficial to root (Pregitzer *et al.*, 2000) and shoot growth (Landhäusser, DesRochers & Lieffers, 2001; Peng & Dang, 2003) of poplars. Neither mounding nor mechanical weed control significantly warmed up soils in our study, however, especially during the summer months when growth is highest (June to August; Figure 4). Elsewhere, mounding increased soil temperatures by about 10% (Nilsson & Örlander, 1999; DesRochers, Thomas & Butson, 2004).

Mounding did, however, significantly reduce damage caused by voles during the 2006 winter, both the number of trees attacked and the severity of girdling (Figure 5). In the northern hemisphere, vole damage usually occurs during high-density population cycles (Cheveau *et al.*, 2004; Huitu *et al.*, 2009). In former times, mounding soil around the base of trees was recommended to create a physical barrier against rodent damage (Knapp & Auchter, 1929, cited in Marsh, Koehler & Salmon, 1990). Delay in the return of competing vegetation on top of the mounds, observed here and in other studies (Löf, Rydberg & Bolte, 2006), creates less optimal habitat for voles. Moreover, since weed control equipment did not come any closer than about 10–25 cm from the base of trees, there were usually thick clumps of weeds at the base of trees in the unmounded plots, providing refuge for rodents (Christian *et al.*, 1997; Moser *et al.*, 2002). Voles can cause important financial losses to plantation managers by reducing wood quality (stem deformation) and increasing tree mortality (Baxter & Hansson, 2001; Huitu *et al.*, 2009).

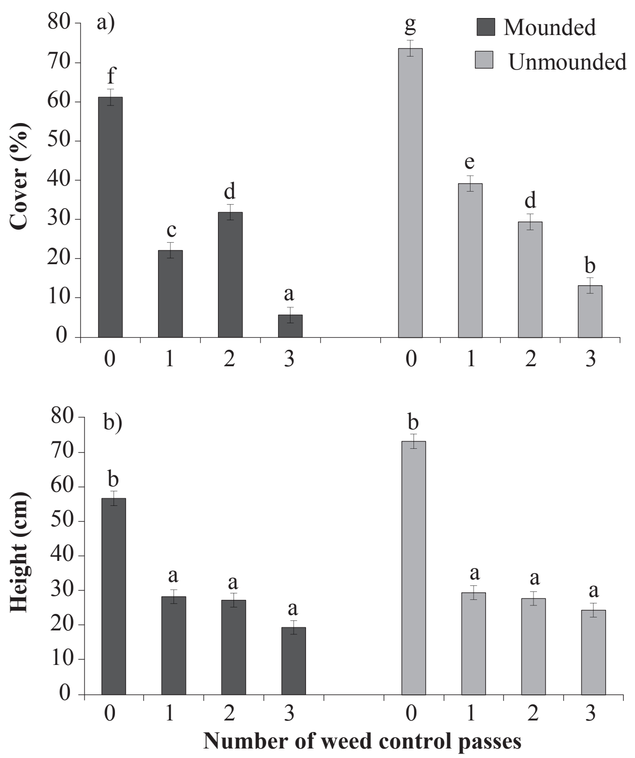

FIGURE 3. Mean percent cover (a) and height (b) of weedy vegetation for each soil preparation (mounded or unmounded) and weed control treatment (0, 1, 2, or 3 passes). Error bars are SE of the mean and bars with the same letter within a graph indicate that means were not significantly different at $P < 0.05$.

Gas exchange measurements (Pn and Gs) often help to explain growth responses to silvicultural treatments; the Gs of trees from clone 915319 increased with weeding (Figure 2b), probably as a result of reduced competition by grasses, which have been found to be very competitive against hybrid poplars for the capture of soil water and nutrients (Coll *et al.*, 2007). This was also supported by the negative correlations found between growth of trees and percent cover and height of weeds for this clone (Table I). The removal of weeds may in turn have positively affected the Pn of trees from clone 915319 in the unmounded plots, where weeds were more abundant (Figure 2b). However, the opposite results obtained for clone 916401 suggest that these 2 clones were differently affected by site conditions created by our treatments.

The importance of weed control in hybrid poplar plantations has been underlined time and time again (Dickmann *et al.*, 2001; Coll *et al.*, 2007; Welham *et al.*, 2007; Pinno & Bélanger, 2009; Bilodeau-Gauthier, Paré & Messier, 2011). However, few studies have looked at mechanical weed control, since herbicides have often proven more effective in eliminating weeds (Aird, 1962; Hansen, Netzer & Rietveld, 1984; Hansen & Netzer, 1985; Buhler *et al.*, 1998; Dickmann *et al.*, 2001; Laureysens *et al.*, 2005). Mechanical weed control, however, can produce added benefits compared to herbicide applications alone, aerating and loosening the soil surface and incorporating organic matter into the soil (Baker & Blackmon, 1978; van den Driessche, 1999). The increased growth of trees (+23% in basal diameter and +12% in height, on average) with weed control would justify mechanical weed control in former agricultural sites, where weedy vegetation can be very competitive. Our results also

TABLE I. Pearson's correlations (*r*) and probability values (*P*) between mean percent cover and height of weeds and height and basal diameter increment of hybrid poplar trees for the 2006 growing season, for each clone.

	Clone 915319				Clone 916401			
	Height (cm)		Basal diameter (mm)		Height (cm)		Basal diameter (mm)	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Cover (%)	–0.15	0.04	–0.35	< 0.001	–0.06	0.40	0.07	0.30
Height (cm)	–0.17	0.02	–0.33	< 0.001	–0.07	0.28	0.05	0.47

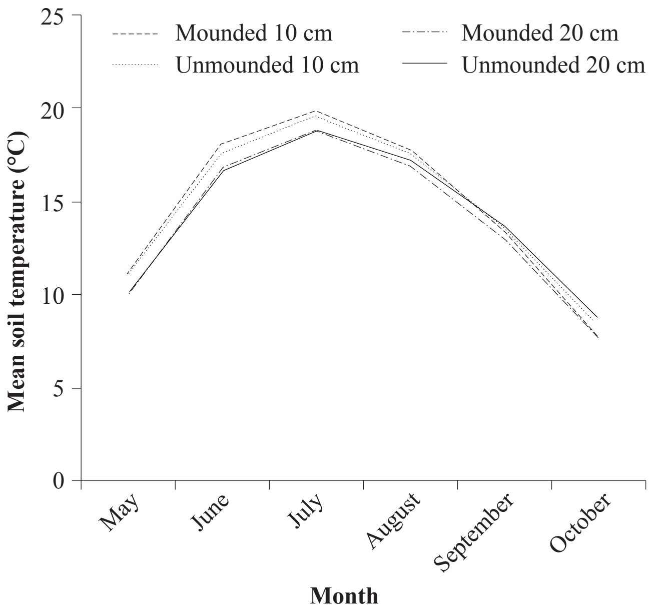

FIGURE 4. Mean monthly soil temperatures averaged for the years 2005 and 2006, for mounded and unmounded plots at 10 and 20 cm soil depth.

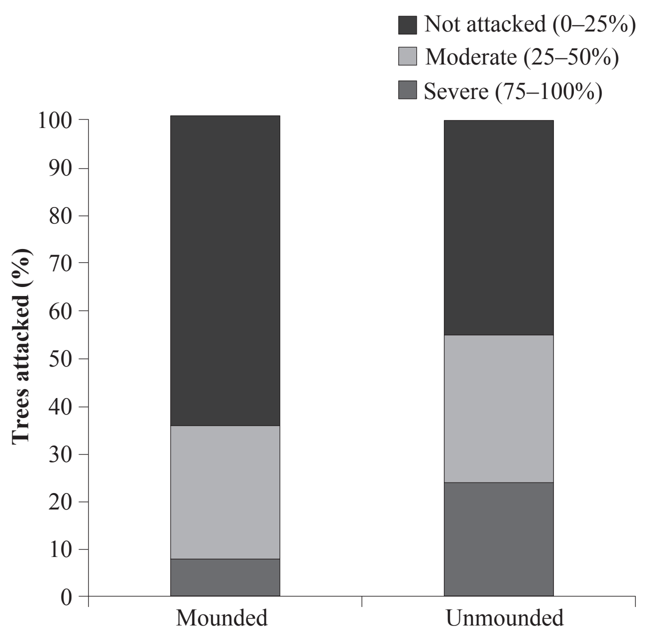

FIGURE 5. Frequency and severity of vole damage caused during the 2005–2006 winter for each mounding (mounded, unmounded) treatment, all clones and weed control treatments combined.

show that a single weed control pass was not sufficient to significantly increase growth of trees, and that the third pass done in 2005 did not further increase growth compared to 2 passes only (Figure 1). Although mounding had limited effects on hybrid poplar growth and soil temperatures, it nevertheless reduced weedy vegetation cover, which was negatively related to growth of trees. Mounding also reduced vole damage, and could be used to reduce risks of vole girdling during the winter, especially when there is no or little weed control.

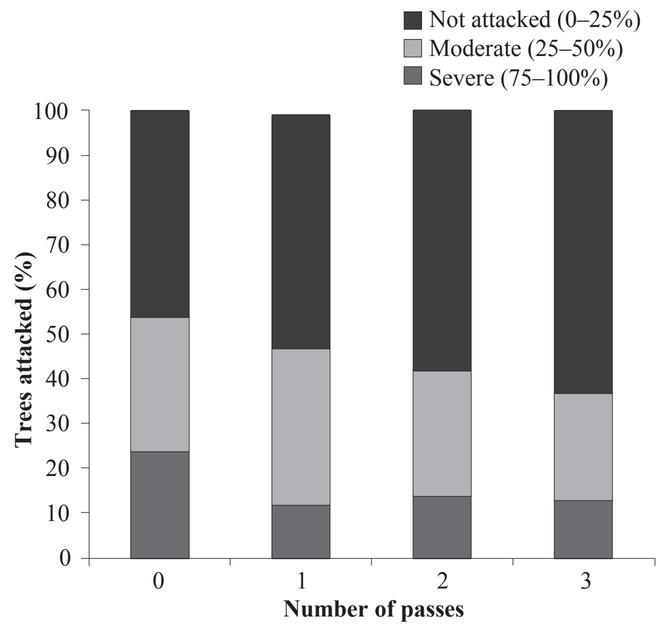

FIGURE 6. Frequency and severity of vole damage caused during the 2005–2006 winter for each weed control (0, 1, 2, or 3 passes) treatment, all clones and soil preparations combined.

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