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The effects of mechanical site preparation and subsequent wildfire on trembling aspen (*Populus tremuloides* Michx.) regeneration in central Alberta, Canada

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Abstract. The objective of this study was to assess the regeneration response of trembling aspen (*Populus tremuloides* Michx.) to different mechanical site preparation (MSP) techniques commonly used in operational forestry (disc trenching, drag scarifying and blading) and the specific microsites created by each treatment. This study was designed to measure regeneration after at least the first two growing seasons, however a large wildfire burned 80% of the study sites at the beginning of the second growing season. Consequently, only limited second year data were presented, but regeneration from the first growing season following the fire was also assessed. Results indicated that microsites where the forest floor was disturbed and the parent root system was only lightly injured were more conducive to suckering than undisturbed microsites or where the root system was severely injured. Also, the fire disturbance after the first growing season resulted in increased suckering relative to the untreated controls in the first year. These results suggest that aspen sites with thick organic layers or vigorous competition from other species can benefit from MSP when applied before the first growing season. In addition, if first year suckering is inadequate, subsequent disturbances such as prescribed fire have the potential to improve suckering provided the parent root system remains intact.

Introduction

Trembling aspen (*Populus tremuloides* Michx.) is a shade intolerant deciduous tree species that typically reproduces through vegetative root suckers (Perala 1990). As a result, aspen often forms clones of genetically identical individuals that are connected through a shallow root system (Day 1944; Strong and LaRoi 1983). Following stand-replacing disturbances such as wildfire or clearcut harvesting, aspen usually regenerates prolifically via root suckering (Bartos and Mueggler 1981, 1982; Crouch 1983; Brown and DeByle 1987) and can produce over 100 000 suckers per hectare in the first growing season (Schier and Smith 1979; Bella 1986). However, in some regions aspen fails to fully regenerate following harvesting (Darrah 1991; Peterson and Peterson 1992), especially if soils are compacted during harvesting (Bates et al. 1993) or if competitive vegetation (e.g., *Calamagrostis canadensis* (Michx.) Beauv.) establishes quickly (Landhäusser and Lieffers 1998). Rapid establishment of high-density sucker stands has been shown to be critical for the maintenance of the clonal root system (DesRochers et al. 2002; Landhäusser and Lieffers 2002), which is important for successful juvenile growth rates and likely for long-term stand development (DesRochers and Lieffers 2001).

Mechanical site preparation (MSP) has been proposed as a treatment option that may increase aspen regeneration following timber harvesting. A number of studies done in the eastern United States and Canada (Zehngraff 1946; Zillgitt 1951; Maini and Horton 1966a; Weingartner 1980; Alban et al. 1994; Lavertu et al. 1994) and western Canada (Frey 2001) have tested the effects of forest floor removal and/or disturbance to the parent root system on the promotion of aspen suckering and have found that when applied prior to the first growing season, these treatments can dramatically increase sucker numbers. In fact, these studies demonstrated that aspen suckering following treatment can be up to 12 times greater than in untreated control areas (Zehngraff 1946). However, some of these previous studies used treatments that are not commonly utilized in operational forestry (e.g., agricultural disking and hand raking) (Zehngraff 1946; Zillgitt 1951; Maini and Horton 1966a; Alban et al. 1994; Lavertu et al. 1994), which may make the results less applicable to forest managers. Further, previous studies did not differentiate between the regeneration successes of different microsites created with MSP.

Fire has also been proposed as a tool for aspen management. Historically, trembling aspen was dependent upon fire for successful regeneration (DeByle et al. 1987; Bonan and Shugart 1989). However, due to the control of wildfires and the fact that many regions do not have extensive prescribed burning programs, fire does not currently play a major role in aspen regeneration (DeByle et al. 1987). Nevertheless, site conditions are normally very favourable for aspen suckering following burning. The forest floor thickness is typically reduced (Horton and Hopkins 1966; Perala 1974; Brown and DeByle 1987; Bonan and Shugart 1989), which tends to increase the depth at which aspen roots will produce suckers (Schier and Campbell 1978; Brown and DeByle 1987). Consequently, prescribed burning has been observed to generate a greater number of aspen suckers per hectare than clearcutting alone (Perala 1974) or clearcutting followed by light intensity scarification (Maini and Horton 1966a).

The objectives of this study were to assess the suckering response of trembling aspen to various MSP treatments commonly used in forestry operations (disc trenching, drag scarifying and blading) and to examine the regeneration responses in the different microsites created by each type of treatment following the first and second growing seasons. A large wildfire, however, burned 80% of the study sites at the beginning of the second growing season. Consequently, only limited second year data was available. However, regeneration data from the first year following the fire are also presented.

Materials and methods

Site description

Four cutblocks 10–20 ha in size located near Slave Lake, Alberta (55°17′N;

114°46′W) were used in this study. Each cutblock was clearcut during the winter of 1999/2000 with a fellerbuncher and grapple skidder and the trees were de-limbed at the roadside. Prior to harvest, the stand composition on each cutblock was at least 90% trembling aspen, with minor components of balsam poplar (*Populus balsamifera* L.), white spruce (*Picea glauca* (Moench) Voss) and paper birch (*Betula papyrifera* Marsh.). Each cutblock was flat or slightly north facing, had thick (>15 cm) organic layers, grey luvisol soils and was in the lower foothills natural ecoregion, low-bush cranberry-aspen ecosite (e2) (Beckingham et al. 1996).

Study design

Ten 90 × 60 m sites were located within the four cutblocks. Each site was uniform in slope and aspect and each was located at least 15 m from the cutblock edge. Each site was divided into four 15 × 60 m treatment strips, with a 10 × 60 m buffer separating each treatment strip. Each of the four treatments (disc trenching, drag scarifying, blading and untreated control) were randomly assigned to one strip within each site, for a total of 10 replicates per treatment.

Post harvest treatments

The three site preparation treatments were carried out with the same prime mover, a John Deere™ 740 skidder (Deere and Company Inc. Moline, IL) between May 3–10, 2000 when most of the ground frost had thawed. The disc trenching was done with rear-mounted hydraulic discs, the drag scarifying used sharkfin barrels that were approximately 160 × 50 cm and 2/3 filled with liquid $CaCl_2$ for additional weight and the blading treatment utilized the straight blade mounted on the front of the skidder. The control strips were left undisturbed, with no vehicle traffic beyond what had occurred during timber harvest.

The objectives of the site preparation treatments were to cause varying levels of organic layer removal and disturbance to the aspen parent root system. Specifically, the disc trenching created trenches approximately 30 cm deep and 50 cm wide, with an elevated berm about 70 cm across on one side and an undisturbed mid-trench area approximately 80 cm wide on the other. There was extensive severing of the parent root system along the edges of the trenches and within the trenches, the top 30 cm of soil and the roots it contained were completely removed. On the berms, the undisturbed root system was buried beneath approximately 20 cm of material. In the mid-trench area, the parent root system was undisturbed, although severed on both sides. The drag scarifying treatment created discontinuous barrel paths approximately 30 cm wide. Within these paths, the organic layer was disturbed and some scuffing and severing injuries were inflicted on parent roots within the top 5–10 cm of mineral soil. The target for the blading treatment was the removal of 1/3 to 1/2 of the organic layer. However, due to the difficulty of carrying out this treatment, three different microsites were created in the blading treatment: shallow scrapes where a portion of the duff layer was removed; deep scrapes where mineral soil was exposed; and piles of material where the skidder blade had been lifted, mostly around stumps. As a result, injury to the parent root system was variable across the blading treatment. In the shallow scrapes, there were limited scuffing injuries to the parent roots at the duff-mineral soil interface. In the deep scrapes, the root system in the top 5–20 cm of mineral soil was extensively scraped or removed. Under the piles, the parent roots were mostly undisturbed, but buried beneath 20–50 cm of material.

At the beginning of the second growing season, a severe wildfire burned 8 of the 10 MSP sites. This fire was discovered on May 23, 2001 and burned approximately 113 000 ha over the next several weeks. The MSP sites were likely burned during the first week of June. This fire was particularly intense as conditions were extremely dry and it occurred following leaf out. Further, this fire burned off the entire forest floor in many areas and as a result, a large proportion of the shallow aspen roots were killed or severely injured.

Field assessments

Immediately following the MSP treatments, 2 H8 Hobo® temperature data loggers (Onset Computer Corp. Bourne, MA) were buried in the upper rooting zone in each treatment strip, for a total of 20 data loggers per treatment and 80 in total.

Additionally, slash levels were measured following treatment. Three 10 m transect lines were randomly located across each control strip. Two 1 m sections of the transect line were randomly selected and each piece of slash intersecting this portion of the transect line was counted and assigned to one of three diameter classes: <0.6 cm, 0.6–2.5 cm and 2.5–7.6 cm. Pieces that were greater than 7.6 cm in diameter were individually measured and recorded along the entire 10 m transect line. The volume of slash on each control strip was calculated:

$$V = n\left[\frac{\pi^2 d_q^{\,2}}{8L}\right]\alpha \tag{1}$$

where V is the volume of slash, n is the number of pieces tallied per diameter class, d_q is the quadratic mean diameter of each diameter class or individually measured piece, L is the length of the sample line and α is the correction term for non-horizontal orientation bias (Brown and Roussopoulos 1974). This formula was applied to each diameter class and each piece of slash greater than 7.6 cm in diameter individually and then the values were summed for each plot. For all sites, slash distribution was relatively even and was estimated to be an average of 88 m^3 per ha over all MSP sites.

In late August of the first growing season (2000), the MSP sites were assessed for regeneration success using two different techniques. First, an overall assessment of sucker density for the 60 × 15 m strips was obtained using standard regeneration survey techniques. Circular plots, 1.78 m radius, were located approximately every 8 m down the centre of each strip. There were 5 plots per strip, for a total of 50 per treatment. The total number of trembling aspen suckers was recorded in each plot, as was the height of the tallest aspen. Secondly, regeneration success was assessed in specific microsites. Microsites were: trenches, berms, and mid-trench areas in the disc trenching treatment, shallow scrapes, deep scrapes, and piles in the blading treatment, barrel paths in the drag scarifying treatment and undisturbed areas in the control. Due to the different microsite shapes, two different plot forms were used. The first was 71 × 71 cm (0.5 m^2) and this was used for all microsites in the disc trenching, blading and control. The second form was 25 × 100 cm (0.25 m^2) and was used for the barrel paths in the drag scarifying. In each case, the plot form was flipped two or four times within the same microsite to make a total plot size of 1 m^2. The trench microsite plots in the disc trenching included the trench and approximately 15 cm on each side of the trench. The other microsite plots assessed the centre of the particular microsite and did not include any transitional areas between microsites. Each microsite plot was located in the closest acceptable microsite relative to the plot centre of the circular regeneration plot. Five plots per microsite were sampled in each treatment strip, for a total of 50 plots per microsite. The number of aspen suckers was recorded, along with the height of the tallest aspen. Additionally, the largest fully developed leaf was collected from the tallest aspen in each plot for leaf size measurement with a LI-COR™ model 3100 area meter (LI-COR Biosciences Ltd. Lincoln, NE).

Both the regeneration and microsite plots were to be remeasured following the second growing season; however, the wildfire burned 8 of the 10 sites. As a result, only the two unburned sites were reassessed for second-year data. In these sites, both the regeneration and microsite plots were repeated and the same information was collected in late August 2001 following the techniques used in the first growing season. However, the plots done in 2001 were not located in exactly the same positions as those completed in 2000. In the sites that were burned, only the control treatment strips were assessed for aspen regeneration.

To monitor soil temperature following the fire, ten H8 Hobo® temperature data loggers were buried in the upper rooting zone in mid June in burned control areas and five data loggers were buried in an unburned clearcut area that was harvested during the winter of 2000/2001.

Statistical analysis

This study was analyzed as a randomized block design testing a single factor- site preparation treatment. Each MSP site was designated as a block, so there were 10 blocks for the first growing season data and 2 blocks for the second year data. There were 5 sub-samples per treatment per block for the sucker density and height data and for the soil temperature data, there were 2 sub-samples per block. The information collected following the fire was not statistically compared to either the first or second year sucker data because of the different growing times and conditions.

The response variables in this study were the number of suckers per ha, average dominant sucker height and average, maximum and minimum daily soil temperatures in each MSP treatment. The number of suckers per ha, average dominant sucker height and average leaf size were also assessed for each microsite within each treatment. Following the second season of growth, mortality and growth rates were the response variables measured in each MSP treatment and in each microsite. For sites burned in the fire, the variables examined were the number of suckers per ha, average dominant sucker height and average, maximum and minimum daily soil temperatures.

The height and leaf area data conformed to the assumptions of normality and equality of variance; however, the number of suckers per ha in both the regeneration and microsite plots did not. Consequently, the sucker density data was natural log transformed. To test for treatment effects, ANOVA procedures using the general linear model in release 8.1 of SAS® (SAS Institute Inc. Cary, NC) were performed. Multiple comparisons were done with the lsd test and a significance level of $\alpha=0.05$ was used for all response variables.

Results

Average daily soil temperature was not affected by site preparation treatment ($P=0.759$); however, both average daily maximum ($P=0.001$) and minimum ($P=0.009$) temperatures were affected. On a monthly basis, the bladed area had the highest maximum temperatures during June and July and the lowest minimum soil temperatures throughout the growing season (Figures 1a and 1b). On average, soil temperature in the blading treatment was 2.5° higher during the day and 1.5 °C lower at night compared to the other treatments.

The fire did not affect average daily soil temperature ($P=0.865$). However, both average daily maximum ($P<0.0001$) and minimum ($P<0.0001$) temperatures were significantly affected by the fire. When analyzed on a monthly basis, the burned sites were 2–3 °C higher during the day and 1–2 °C cooler at night than unburned areas (Figures 2a and 2b).

As evaluated by the circular regeneration plots, the site preparation treatments significantly increased the overall number of suckers per ha compared to untreated control areas following the first growing season (2000) ($P<0.0001$). The disc trenching produced 86 100 suckers per ha, the blading 75 800, the drag scarifying 50 680 and the control generated 27 840 aspen suckers per ha (Figure 3). There was no difference in average dominant sucker height among treatments ($P=0.638$); all were approximately 95 cm tall one growing season following treatment.

Following the wildfire, aspen regeneration averaged 59 325 stems per hectare (Figure 3) and average dominant sucker height was 83 cm following one season of growth (2001).

Microsites significantly affected the number of suckers generated in the first growing season (2000) ($P<0.0001$). Trenches in the disc trenching treatment, shallow scrapes in the blading treatment and barrel paths in the drag scarifying treatment generated the greatest number of suckers, while piles in the bladed areas and the control produced the fewest (Figure 4a).

There was also a significant difference among dominant sucker heights in each microsite ($P<0.0001$). Trenches in the disc trenching treatment and shallow scrapes in the blading treatment produced the tallest suckers at approximately 80 cm,

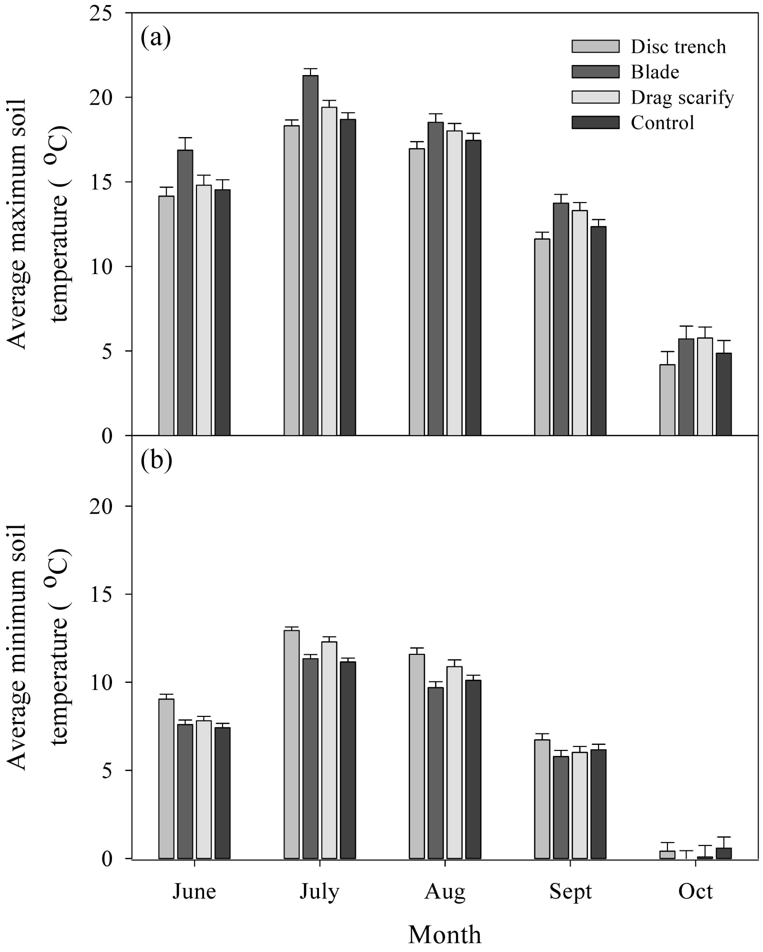

Figure 1. Average monthly maximum (a) and minimum (b) soil temperatures in the rooting zone during the first growing season after mechanical site preparation (2000).

whereas berms in the disc trenching treatment and piles in the blading treatment generated the shortest suckers at approximately 34 cm (Figure 4b).

Average leaf size was also significantly affected by microsite ($P<0.0001$). The trench microsite in the disc trenching treatment and the shallow scrapes in the blading treatment produced suckers with the largest leaves at about 38 cm^2, while suckers from the piles in the bladed areas had the smallest leaves (16 cm^2, Figure 4c).

For the two MSP sites surviving to the second growing season, no differences were detected in mortality rates ($P=0.827$) or height growth rates ($P=0.467$) among site preparation treatments in the regeneration plots. On average, mortality was negligible and the suckers grew approximately 50 cm to a total maximum height of

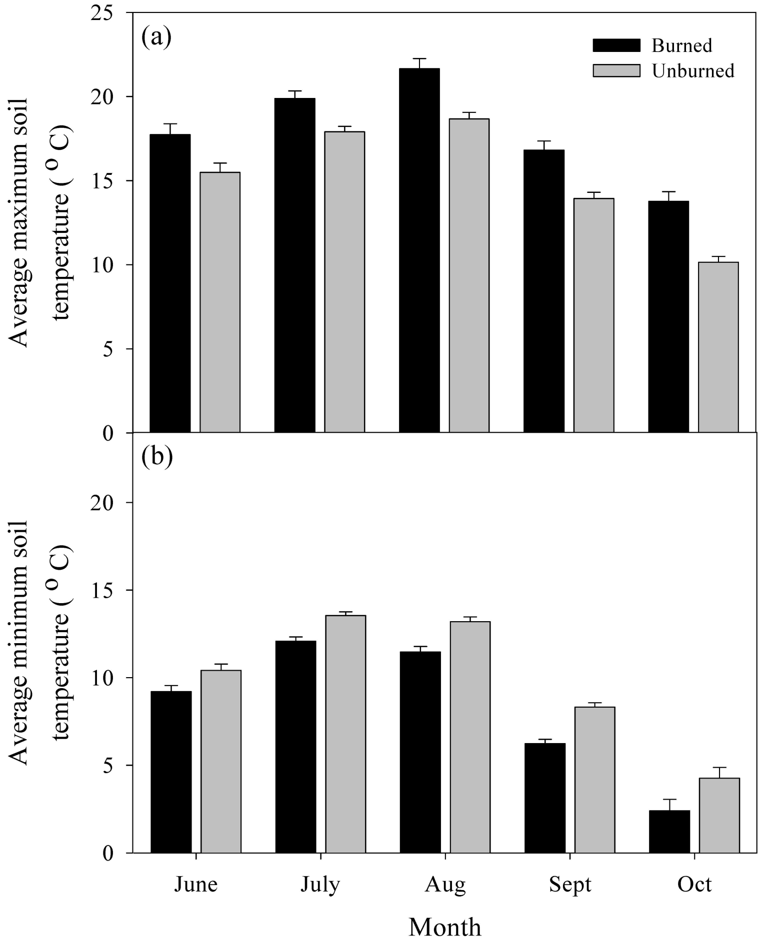

Figure 2. Average monthly maximum (a) and minimum (b) soil temperatures in the rooting zone during the first growing season after a wildfire in burned and unburned areas (2001).

about 140 cm across all treatments. There was also no difference in either mortality rates (P=0.742) or growth rates (P=0.310) among microsites in the microsite plots. In these plots, suckers grew an average of 24 cm and had an average mortality of 23%.

Discussion

Mechanical site preparation dramatically increased aspen suckering following timber harvesting. These results concur with earlier studies which found that treatments that reduced the forest floor thickness and/or injured the parent root system lead to increased suckering relative to untreated control areas (Zehngraff

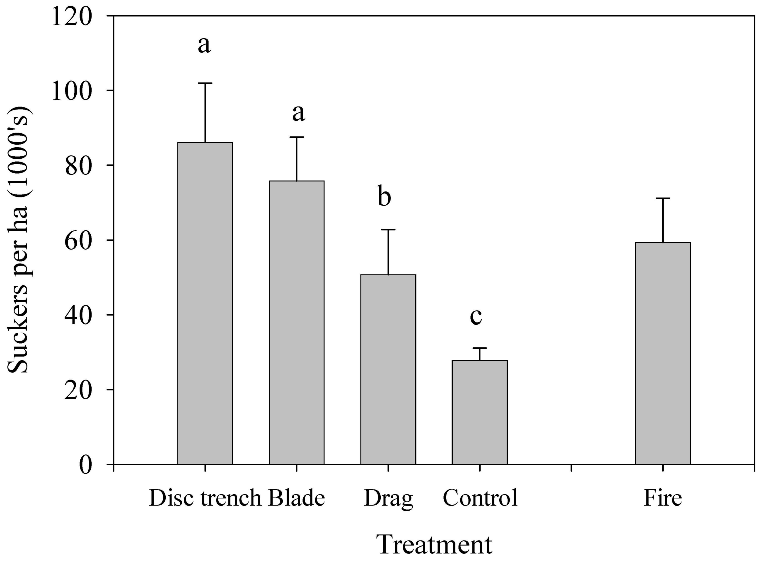

Figure 3. Number of suckers per hectare in regeneration plots following the first growing season after mechanical site preparation (2000) and wildfire (2001). The wildfire occurred at the beginning of the second growing season.

1946; Zillgitt 1951; Maini and Horton 1966a; Weingartner 1980; Alban et al. 1994; Lavertu et al. 1994; Frey 2001). Further, this study demonstrated that microsites where the parent root system was disturbed but not extensively damaged (e.g., shallow scrapes in blading treatment, barrel paths in drag scarifying treatment) resulted in greater suckering than those where the root system was undisturbed (e.g., mid-trench in disc trenching treatment, control) or severely damaged (e.g., deep scrapes in blading treatment).

It has generally been assumed that soil temperature is the most important environmental factor driving aspen suckering following a stand-replacing disturbance (Horton and Maini 1964; Maini and Horton 1966b; Steneker 1974, 1976; Hungerford 1988). However, in our study there were no significant differences in average daily soil temperatures and there were differences of only 2.5° and 1.5 °C in daily maximum and minimum temperatures among treatments, respectively. Since aspen suckering on root segments has been observed to be relatively insensitive to small changes in daily maximum temperature between 12° and 20 °C (Fraser et al. 2002), the minor changes in soil temperature that followed MSP would likely not account for the large differences in sucker numbers. Instead, other factors may be involved in sucker initiation and early growth under field conditions.

Injury to the parent root system of living trees has been noted to stimulate aspen suckering under controlled conditions (Farmer 1962) and it has also been speculated that it would promote suckering in the field following harvesting (Maini and Horton 1966a; Steneker 1974; Shepperd 1996). Injury to the root system may prevent or reduce the flow of sucker-inhibiting hormones within the roots, thus encouraging

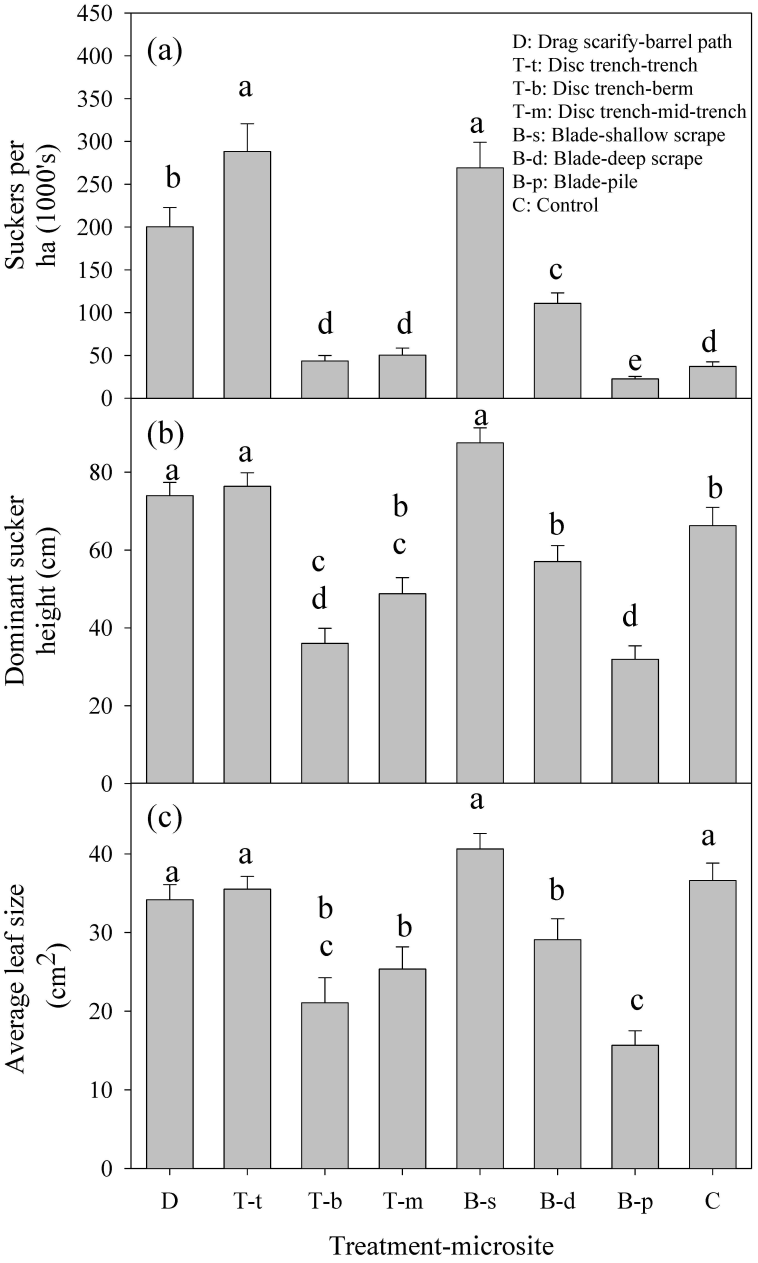

Figure 4. Number of suckers per hectare (a), average dominant sucker height (b) and average leaf size (c) in microsite plots following the first growing season after mechanical site preparation (2000).

formation of suckers (Farmer 1962; Maini and Horton 1966a). As the majority of aspen roots are contained within the top 12 cm of mineral soil (Kemperman 1978; Schier and Campbell 1978), treatments that disturb this portion of the soil profile would likely reduce the flow of hormones and lead to increased aspen suckering. However, excessive disturbance has been shown to be detrimental to aspen growth and survival (Steneker and Walters 1971; Perala 1978), which corresponds with the results from our microsite plots. It is also possible that nutrient availability affects aspen suckering following MSP. Soil nutrient availability tends to increase immediately following site preparation (Vitousek et al. 1992; Schmidt et al. 1996) and high soil nutrient status has been observed to increase initial aspen growth rates (Gifford 1967; Lu and Sucoff 2001; Fraser et al. 2002). Therefore, it would be logical to expect that the increase in nutrient availability that typically follows MSP could lead to an increase in initial aspen growth rates.

Control plots in the 8 burned sites generated approximately 60 000 suckers per ha in the first season of growth following the fire (second season after logging), which was similar to the number stimulated by MSP carried out immediately following harvesting and was approximately double the number generated following no site preparation. The average dominant sucker height, however, was lower following the fire than after MSP (83 vs. 95 cm). This reduced height could be due to the fact that developing suckers used stored root carbohydrate reserves for initial growth (Tew 1970; Schier and Zasada 1973), likely making root reserves lower following the fire than immediately after MSP. Alternatively, the reduced height could be attributed to the fact that suckers tend to arise from deeper roots following a severe fire (Schier and Campbell 1978; Brown and DeByle 1987) and would, therefore, appear shorter than those originating from shallower roots on unburned sites.

Sites with cool insulated soils often do not produce well-stocked sucker stands following a severe disturbance in the boreal forest (personal observation). Since the sites selected for this study had thick organic layers and cool soil temperatures, the relatively abundant sucker regeneration observed in the control areas was unexpected. It is likely that the number of suckers present in the untreated control areas following the first growing season (27 840 suckers per ha) would be sufficient to produce a well-stocked mature stand. However, there is currently no information on the minimum number of suckers required to produce a well-stocked mature aspen stand in the boreal forest. It has been shown, however, that following a severe disturbance, maintenance of the clonal root system is critical for early aspen sucker growth and survival as clones with greater root biomass per sucker exhibited improved growth rates compared to those with smaller clonal root systems (DesRochers and Lieffers 2001). Further, it has been suggested that the rapid development of high sucker leaf areas, through high initial densities, is necessary for the maintenance of the root system because large quantities of photosynthate are required to support the respiration demands of the root system (DesRochers et al. 2002; Landhäusser and Lieffers 2002). Therefore, the establishment of high-density sucker stands is important for rapid juvenile growth and probably for successful long-term stand development. Additionally, establishing large numbers of suckers per ha immediately following a stand-replacing disturbance would aid in site capture, thus reducing the vigour of other pioneer species like *Calamagrostis canadensis*(Lieffers et al. 1993; Landhäusser and Lieffers 1998) and improving the growing conditions for aspen.

Management implications

This study demonstrates that mechanical site preparation can successfully be used to regenerate aspen stands following timber harvesting. While it is not necessary to treat all aspen cutblocks prior to suckering, those sites with thick organic layers or high brush hazards could benefit from treatment with any of the techniques used in this study. However, these results also demonstrate that certain microsites are more conducive to suckering than others. Treatments that disturb the soil above the parent root system, without seriously damaging the roots (e.g., drag scarifying or shallow blading), would likely be the best treatment options. This study also shows that aspen regeneration could be promoted with fire even after the first growing season following harvesting. Consequently, if aspen regeneration is inadequate following the first season of growth, forest managers could carry out a prescribed burn (or perhaps MSP) prior to the second growing season and expect better suckering, provided the parent root system remains intact.

This study also has implications for mixedwood management. In the Canadian prairie provinces, trembling aspen and white spruce generally dominate mixedwood stands (Rowe 1972). When spruce regeneration is desired following harvesting on mixedwood sites, cutblocks are typically mechanically site prepared and planted with spruce (Day and Bell 1988; Navratil et al. 1991; Lieffers and Beck 1994). However, the choice of site preparation is critical to ensure a balance between spruce and aspen regeneration. Our results have demonstrated that aspen regeneration is most vigorous following treatments that disturb but do not remove the entire forest floor. Consequently, if some control over aspen were desired in order to allow for spruce regeneration, the moderate intensity treatments would likely be inappropriate choices. Instead, it would be more beneficial to plant spruce seedlings without site preparation or to carry out a more intense treatment that would seriously disturb the aspen parent root system in small areas but not seriously injure it over an entire cutblock.

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