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Impact of Slash Loading on Soil Temperatures and Aspen Regeneration

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Impact of Slash Loading on Soil Temperatures and Aspen Regeneration

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ABSTRACT

Natural regeneration is the primary method used to restock trembling aspen (*Populus tremuloides* Michx.) cutblocks and the effects controlling this regeneration are increasingly becoming areas of both interest and concern to the forest industry. Harvest operations in Manitoba require that all coarse woody debris or "slash" be left and distributed in cutblocks, which significantly affects soil surface conditions by potentially altering soil temperatures and thus aspen suckering. The objective of this study was to investigate the relationships between slash loading and soil temperatures and the implications for harvest operations.

Initiation of aspen suckers in the Duck Mountain ecoregion seems to occur mainly from parental roots located in the LFH layer. In winter cutblocks, the mean depth to sucker initiation from the parent root was only 4.6 ± 2.4 cm. In the summer cutblocks, the mean depth to sucker initiation occurred at 3.4 ± 2.1 cm. Although there was some variability in depth to suckering, the suckering consistently occurred from within the LFH layer and at a relatively shallow position within the soil profile. This shallow depth to sucker initiation has important implications for harvest operations using heavy machinery especially those occurring during the summer season.

In order to examine the effects of slash loading on soil temperature, soil temperature probes were installed under three levels of slash in winter cutblocks [no slash (0 - 5 kg m^{-2}), moderate slash (5 – 30 kg m^{-2}), and heavy slash (30 – 110 kg m^{-2})] and four levels of slash in summer cutblocks [no slash (0 - 5 kg m^{-2}), moderate slash (5 – 15 kg m^{-2}), heavy slash (15 – 30 kg m^{-2}) and very heavy slash (30 – 80 kg m^{-2})]. Daily mean soil temperatures during the growing season were significantly lower under higher levels of slash. Higher amounts of slash also significantly shortened the length of the growing season and the number of hours each day where soil temperatures reached 15 ^{o}C (minimum soil temperature required for aspen suckering to thrive). Increased levels of slash loading also decreased the number of suckers produced, the leaf area index and the sucker volume. Although the summer cutblocks had lower amounts of slash loading, the negative effects of increased slash loading occurred at lower levels than in the winter cutblocks. Moderate levels of slash in summer cutblocks, and heavy levels of slash in winter cutblocks limit aspen sucker growth and production.

The extent of slash loading across both winter and summer cutblocks in the Duck Mountain ecoregion was determined using two line intercept methods. The winter cutblocks had a significantly higher amount of slash (ranging from 6.74 to 10.42 kg m^{-2}), than the summer cutblocks (which ranged from 4.58 to 6.96 kg m^{-2}). The mean amount of slash found in winter cutblocks corresponds with the moderate slash loading category which was found to have some effect on soil temperatures but little effect on aspen regeneration. The mean amount of slash found in the summer cutblocks also corresponded to the moderate slash loading category; however, moderate levels of slash in summer cutblocks did significantly decrease both soil temperatures and aspen regeneration.

Extensive aspen sucker production within the first few years of regeneration is essential in order to ensure that a healthy stand is produced. Ensuring that slash is distributed evenly in cutblocks may decrease the negative effect on aspen suckers and on aspen root systems. Harvest operators should avoid creating high levels of slash in winter cutblocks and moderate levels of slash in summer cutblocks. The use of a visual slash loading guide for harvest operators is recommended in order to prevent the occurrence of slash loads with detrimental effects.

Since increasing amounts of slash also effectively dampen the daily temperature cycle, this was thought to have some effect on aspen suckering. A growth chamber study was conducted examining the effects of diurnal temperature variation on aspen sucker initiation and initial production. Using field temperature data as a guideline, three temperature conditions were established: 15 ^{o}C daily mean with no diurnal fluctuation, 15 ^{o}C daily mean with 1.5 ^{o}C diurnal fluctuation, and 15 ^{o}C daily mean with 3.5 ^{o}C diurnal fluctuation. After aspen root pieces were grown in the growth chambers under the conditions listed above for an eight week growth period, analysis of the data indicated that there was no significant difference on aspen sucker production between any of the treatments. This indicates that although slash loading does cause a dampening effect on diurnal temperatures, this dampening in the amplitude of the daily temperature may not be the reason for the decrease in sucker production associated with increased levels of slash loading.

ACKNOWLEDGEMENTS

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INTRODUCTION

Trembling aspen (*Populus tremuloides* Michx.) thrives in a broad range of climatic conditions and occurs across the North American continent. In Canada, trembling aspen is the commercially important hardwood tree species. However, the area where trembling aspen grows large enough to be commercially important only occurs in a large band across the prairie provinces (Peterson and Peterson 1992). The areas of harvestable wood are broken up into several forest management land use areas managed by different companies. Louisiana-Pacific Canada (L-P) harvests 900, 000 m^3 of wood each year from FML #3 in the Duck Mountain ecoregion of west central Manitoba for the production of oriented strand board (OSB). The majority of the wood harvested in this FML is trembling aspen. As with many other companies harvesting aspen, successful regeneration of productive aspen forests is an area of concern.

Because of the strong pioneering capability of aspen and its ability to regenerate asexually, natural regeneration is the primary method incorporated to regenerate these hardwood forests after clear cutting. Several factors control the asexual reproduction of aspen, that is, the suckering quantity and quality. The two main factors known to control aspen suckering are apical dominance and soil temperature. When mature trees are cut, apical dominance is removed and soil temperature becomes the fundamental factor controlling aspen regeneration. Any changes in soil temperature will affect the ability of aspen clones to produce a sustainable amount of suckers from their root system. Soil surface conditions can significantly affect soil temperature and soil temperature fluxes. Harvesting methods have the potential to alter soil temperature and thus aspen suckering. To ensure the reproduction of productive forests, harvest operations must be considered in terms of their ability to alter the soil surface.

Present operations in the Duck Mountain ecoregion are predominantly tree length harvest operations with delimbing occurring at the stump. As trees are cut and prepared for transport from the cutblock, tree tops, branches and other course woody debris are distributed throughout the cutblock according to the feller buncher cutting pattern. The amount of slash left after harvest operations is an area of great interest for companies such as L-P since slash may alter aspen reproduction in both softwood stands and hardwood stands (Steneker 1976; McInnis and Roberts 1995; Bella 1986; Navratil 1996). In addition, as of May 1, 1993, Manitoba Natural Resources Forestry Branch has put into place a policy which requires that slash be spread out in the cutblock. Furthermore, this policy also prohibits the incidence of landing areas with roadside debris piles. Consequently, there is an increasing awareness and concern regarding the severity of effects of slash and slash distribution on forest renewal. Although several authors have individually addressed the issues of slash cover, aspen reproduction and soil temperature, no previous studies have been done which quantify the effects of different levels of slash loading on soil temperatures and on aspen suckering.

The influence of slash loading on soil temperatures in the Duck Mountain ecoregion is of great concern for the production of healthy hardwood forests. This project attempts to clarify the effects of slash loading on soil temperature and aspen regeneration in the Duck Mountain ecoregion by investigating several important relationships. The study objectives are: (1) examine the relationships between slash loading and soil temperatures, (2) examine the relationship between slash loading and aspen regeneration, (3) examine the relationship between slash loading and the pattern of sucker initiation, and (4) examine the effects of diurnal temperature fluctuation on aspen suckering potential.

MATERIALS AND METHODS

Study Area

The study area was located in the Duck Mountain ecoregion of west-central Manitoba ($57^{o}02'$-$57^{o}48'$ north and 350^{o}-385^{o} east). The forests of this area are predominantly deciduous with mixed deciduous and coniferous forests at higher elevations. The lower elevations of the Duck Mountain ecoregion (300-400 m) predominantly consist of Chernozemic soils while soils at higher elevations (400-700 m) are largely composed of Gray Luvisolic soils (Zoladeski et al. 1995).

The Duck Mountain ecoregion consists largely of hardwood stands at the lower elevations and some conifer dominated stands at the higher elevations. Tree length harvesting is the conventional harvest operation used in this FML, resulting in the slash being retained on site and distributed according to the feller-buncher pattern. According to policies implemented in Timber Sale Agreements, made between L-P and timber operators, all logging debris must be distributed so that it lays as close to the ground as possible and no roadside debris piles or in-bush debris piles are permitted. Harvest operations in FML #3 occur during both winter and summer seasons.

In order to examine the effects of slash loading on soil temperature regimes, aspen regeneration, and depth to sucker initiation twelve newly harvested hardwood cutblocks located within FML #3 were chosen for sample study areas. Six of these cutblocks were harvested during the winter season while the other six were harvested during the summer season. Before harvesting, all 12 of these cutblocks were composed of mature, well stocked, aspen dominated stands (Table 1).

Table 1. Pre-harvest stand characteristics of field study sites located throughout the Duck Mountain Ecoregion

Site	Harvest Season	S-Type	V-Type	Species Composition	Area (ha)	Site Class	Crown Closure
Madge Lake	Winter	6	5	TA10	3.55	1	4
				TA8WB2	4.83	1	4
				TA6BA2BS1BF1	44.51	1	4
Arm Lake	Winter			TA7WS2BA1	37.3	1	4
				TA8WS1BS1	10.6	1	4
				TA7BF3	0.4	1	2
Route H	Winter	10	5, 1, 0	TA8WB1WS1	25.6	1	4
				TA8WB2	6.1	1	
West Favel	Winter			TA8WS1BF1	35.2	1	4
				TA10	3.6	1	2
				WS6TA4	0.3	1	4
Minnitonas Creek 1	Winter	6, 10	5, 1	TA9WS1	27.8	1	4
				TA8WB2	5.2	1	3
				TA8BF1BS1	12.3	1	2
Minnitonas Creek 2	Winter	4, 10	4, 5, 1, 0	TA8BA1WB1	2.5	1	4
				TA8BF2	20.4	1	4
				TA9WS1	3.0	1	4
				TA8WB2	2.4	1	3
				TA9WS1	9.8	1	3
Watjask	Summer	10	8, 5	TA8WS2	33.1	1	4
Cryderman's Pit	Summer	4	5	TA6BA1WB1WS1BF1	33.4	1	4
Route W	Summer	10, 6	5	TA8WS2	19.5	1	4
				TA8WS2	7.9	1	3
Wine Lake	Summer	5, 8, 1	5, 1	TA7WB2BF1	34.0	1	5
				TA8BA2	5.9	1	4
				TA7BA1WS1BF1	26.0	1	4
				TA6WS4	0.9	1	3
Ethelbert Trail	Summer	10	5	TA8BA2	42.6	1	4
Upper Dam	Summer	4, 5	5, 8	TA7BS1WS1BF1	87.1	1	4

Extent of Slash Loading Across Winter and Summer Cutblocks

Two methods were used to determine the average amount and distribution of slash left in both the winter and summer cutblocks. The first method used was a modified line intercept method. The total length of slash in a 1 m^2 plot was quantified using the line intercept method developed by Newman (1966). The 1 m^2 plot area was surveyed using vertical lines and horizontal lines spaced every 20 cm. Slash in each of the 1 m^2 plots was counted separately based on the following diameter classes: <1.0 cm, 1.0 - 4.9 cm, 5.0 - 9.9 cm, 10.0 – 20.0 cm and >20.0 cm. The total length of slash was converted to mass by determining a unit biomass estimate for each diameter class. In order to determine the unit biomass, samples from each diameter class were collected from cutblocks dried and measured. This unit biomass, or density measurement, in combination with the total length estimated with the line intercept method were used to calculate the total biomass in each of the 1 m^2 areas surveyed. Thirty 1 m^2 quadrats were randomly located in each of the 12 cutblocks and an average slash loading was estimated for each cutblock. The second method used to determine the average amount of slash in each cutblock was the Fuel Loading Method (McRae et al. 1979). This line intercept method was developed in order to characterize fuel characteristics to model forest fire behaviour. In each cutblock, three equilateral triangles, measuring 30 m on each side, were sampled in order to represent the average slash load for that cutblock.

Pattern of Sucker Initiation

Suckering pattern and suckering depth as affected by slash loading and soil temperature was examined across all twelve cutblocks. In each cutblock, three randomly assigned 100 m transects were used to excavate suckers at 10 m along each transect. At each excavation, the depth of forest floor, depth to sucker initiation, location of initiation from the parental root, and estimation of slash above the sucker (using the modified Newman line intercept method) were recorded.

Impact of Slash Loading on Soil Temperature and Aspen Regeneration

Three 1 m^2 plots were established in each of the six winter and six summer cutblocks to investigate soil temperatures using Hobo temperature probes (Hobo H8 Pro Series; 2 channel). The internal temperature probe was installed at the LFH – mineral soil interface and the external temperature probe at 10 cm below the LFH - mineral soil interface. Temperature readings were taken at 30 minute intervals. In each cutblock, one plot was established in an area with no slash loading, moderate slash loading and heavy slash loading. Each of these three levels of slash loading was chosen based on visual estimation. Later the actual amount of slash above each probe was determined using the modified Newman line intercept method. The use of this method allowed for slash quantification of a small area above each probe (1 m^2) whereas the Fuel Loading Method can only be used on a larger scale.

When the three levels of slash load in each cutblock were quantified with the modified Newman line intercept method, it was clear that the visually established plots were fairly accurate at delineating slash loading categories. In the winter cutblocks, the "no slash" load was less than 5 kg m^{-2} (0 - 50 t ha^{-1}), the "moderate slash" load was approximately 5 - 20 kg m^{-2} (50 - 200 t ha^{-1}) and the "heavy slash" load was approximately 20 - 110 kg m^{-2} (200 t ha^{-1} - 1100 t ha^{-1}). In the summer cutblocks, the "no slash" load was less than 5 kg m^{-2} (0 - 50 t ha^{-1}), the "moderate slash" load was approximately 5 - 15 kg m^{-2} (50 - 150 t ha^{-1}) and the "heavy slash" load was approximately 15 - 30 kg m^{-2} (150 - 300 t ha^{-1}). Although the "heavy slash" load in the summer cutblocks was substantially lower than the "heavy slash" load in the winter cutblocks, it was consistently estimated so these values were considered an accurate representation of "heavy slash" loads in summer cutblocks. Initially, a total of 18 probes were placed in winter cutblocks and 18 probes in summer cutblocks, but after noting that the slash in summer cutblocks appeared to be lower than in winter cutblocks, an additional plot of "very heavy slash" load was established in each of the six summer cutblocks.

The 1 m^2 area above each probe was also used as the sampling area for aspen regeneration. In order to increase the sample size and thus precision of our aspen regeneration success estimates, one additional plot was established in each cutblock at each level of slash loading (none, moderate and heavy). Aspen regeneration success in each of the 1 m^2 plots was evaluated by measuring number of suckers per 1 m^2 plot, mean sucker height per 1 m^2 plot, mean sucker diameter at the root collar per 1 m^2 plot, and Leaf Area Index (LAI) per 1 m^2 plot.

Diurnal Temperature Fluctuations

Because slash loading results in a layer that insulates the soil surface, the soil temperatures under heavy slash loading should result in a dampening effect on the diurnal temperature cycle. Field temperature measurements from slash loading plots were examined to establish day and night time temperature extremes and the time of their occurrence during the daily cycle. This data was used in a growth chamber study which investigated the effect of diurnal extremes on the suckering of aspen roots.

For the growth chamber study, 10 cm long aspen root cuttings (1.0 $\pm$ 0.5 cm diameter) were obtained from six mature stands on Luvisolic soils in the Duck Mountain ecoregion. Root cuttings were excavated, transplanted, and grown in a growth chamber for eight weeks. Root cuttings were planted at 4 cm depth since the optimal depth for maximum suckering response ranged from 4-6 cm (Johansson and Lundh 1988; Farmer 1963).

Three temperature regimes were established in three separate growth chambers. One growth chamber had a constant temperature of 15 ^{o}C with no diurnal fluctuation. The second chamber had a daily mean temperature of 15 ^{o}C but a diurnal fluctuation of 1.5 ^{o}C (daily maximum of 16.5 ^{o}C and daily minimum of 13.5 ^{o}C). This second chamber was representative of soil temperature conditions at the LFH-mineral soil interface under a "heavy slash" load across the twelve cutblocks. The third growth chamber again had a daily mean temperature of 15 ^{o}C but a diurnal fluctuation of 3.5 ^{o}C (daily maximum of

18.5 °C and daily minimum of 12.5 °C). This third chamber had similar soil temperature conditions to those found under "no slash" load across the twelve field sites. Each temperature condition was replicated in two separate growth chambers (a total of six growth chambers).

Pots were randomly distributed and redistributed throughout the growth chamber. The success of aspen regeneration under the tree different conditions was determined by measuring the number of suckers per 10 cm cutting, number of suckers sprouted which did not reach the soil surface, dry weight of suckers, diameter of sucker stem at root collar, and height of suckers.

RESULTS

Extent of Slash Loading Across Winter and Summer Cutblocks

Using the modified Newman line intercept method of slash estimation, winter cutblocks had a mean slash load of 10.42 kg m^{-2} while summer cutblocks had a mean slash load of 6.96 kg m^{-2} (Table 2). Using the Fuel Loading method, winter cutblocks had a mean slash load of 6.74 kg m^{-2} and summer cutblocks had a mean slash load of 4.58 kg m^{-2}. Both slash estimation methods indicated that summer cutblocks had a significantly lower amount of slash left on the cutblocks after harvest than winter cutblocks ($P=0.01$ and $P=0.00$, respectively). Analysis of the estimated amounts of slash in each category, using the modified Newman line intercept method, indicated that on average, the 1.0 - 4.9 cm diameter category was represented in the largest amount on both winter and summer cutblocks (Table 2). In both the winter cutblocks and the summer cutblocks, the 10.0 – 20.0 cm diameter category contributed the second highest amount of biomass to the total amount of slash left on the cutblocks (Table 2).

According to our visually selected slash load categories, the mean amount of slash in the winter cutblocks (10.42 kg m^{-2} or 6.74 kg m^{-2}) falls into the "moderate slash" load category (5 – 20 kg m^{-2}). In the summer cutblocks the mean slash load using the modified Newman line intercept method (6.96 kg m^{-2}) also falls into the "moderate slash" load category (5 –15 kg m^{-2}) and using the Fuel Loading Method (4.58 kg m^{-2}), the mean slash load lies just under the "moderate slash" load category. Using the modified Newman line intercept method, 14% of the sampled plots were in the "heavy slash" load category (20 – 110 kg m^{-2}) in the winter cutblocks. In the summer cutblocks, 11% of the sampled plots were in the "heavy slash" load category (15 – 30 kg m^{-2}).

Table 2. Average biomass of slash (kg m^{-2}) in each of the five diameter classes in winter and summer cutblocks using the modified Newman line intercept method of slash estimation

	Mean slash biomass (kg m^{-2})					
	<1 cm	**1 - 4.9 cm**	**5 - 9.9 cm**	**10 - 20 cm**	**>20 cm**	**Total**
Winter cutblocks	0.32	3.39	1.79	3.31	1.62	10.42
Summer cutblocks	0.42	2.11	1.64	1.85	0.94	6.96

Pattern of Sucker Initiation

In the winter cutblocks, the mean depth of the LFH layer was 10.4 $\pm$ 4.2 cm and the mean depth to sucker initiation from the parent root was 4.6 $\pm$ 2.4 cm. In the summer cutblocks, the mean depth of the LFH layer was 5.9 $\pm$ 2.6 cm and the mean depth to sucker initiation from the parent root was 3.4 $\pm$ 2.1 cm. In all the suckers that were excavated across both the winter and summer cutblocks, only 7% of the suckers had initiated from parental roots below the LFH layer within the soil profile. Across these 12 cutblocks, aspen sucker initiation occurred on those parental roots which were located very near the soil surface. Additionally, of all the suckers that were excavated in both the winter and summer cutblocks, 68% had initiated from the top, 28% from the sides, and only 4% from the bottom of the parental root.

Maini and Horton (1966) showed that decreasing soil temperatures resulted in significantly less aspen sucker growth. Because of this significant response to decreasing soil temperatures, we expected that higher amounts of slash would be associated with lower soil temperatures and thus the depth to suckering would decrease. However, suckering depth does not seem to be affected by the amount of slash in either the winter (Figure 1) or the summer cutblocks (Figure 2). Figure 1 seems to indicate that the depth to suckering increased in those categories with > 30 kg m^{-2} slash, however, this is likely because of the very small sample size in these categories ($n < 3$). The lack of response of depth to sucker initiation to increasing slash loads may be due to the inherent distribution of aspen parental root systems in the soil profile. All of the suckers we excavated had initiated from roots within the top 15 cm of the soil profile, however, aspen roots have been found to extend to depths of 1.2 m within soil profiles (Van Rees 1997; Stone and Kalisz 1991). While it is possible that the suckering could have occurred from roots that were located lower within the soil profile, our random excavation method did not encounter any of these. Additionally, it may be that in the sample areas covered with a heavier load of slash, there may not have been any parental roots near the surface to sprout from. Perala (1991) and Peterson and Peterson (1992) indicated that the majority of suckering occurs on aspen roots located in the upper 12 cm of the soil profile, Navratil (1996) indicated that sucker initiation occurred at depths of 8-15 cm in the field while Farmer (1962) and Kemperman (1978) indicated that in field conditions, most suckers occur at 1-3 cm root depth. Clearly, there is immense variability among aspen clones and aspen suckering responses.

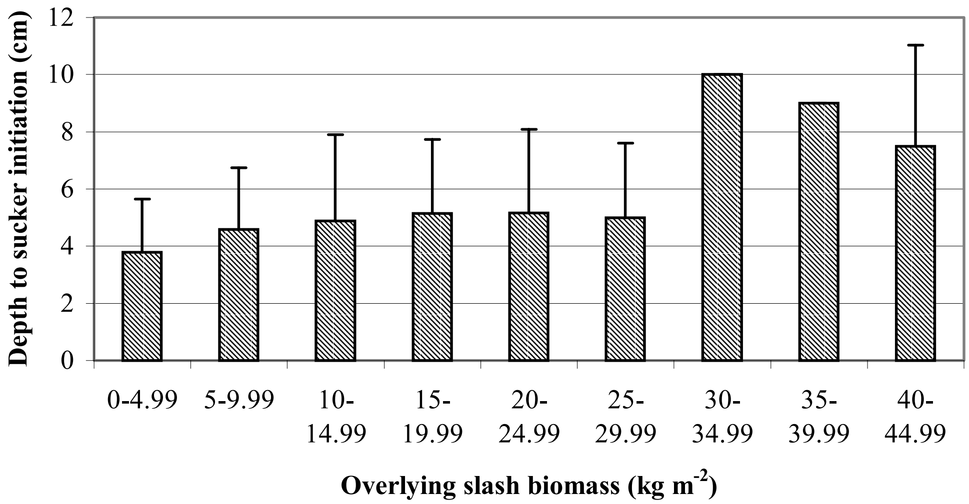

Figure 1. Mean depth of sucker initiation from the parental root to the soil surface of aspen suckers excavated from under varying loads of slash in winter cutblocks.

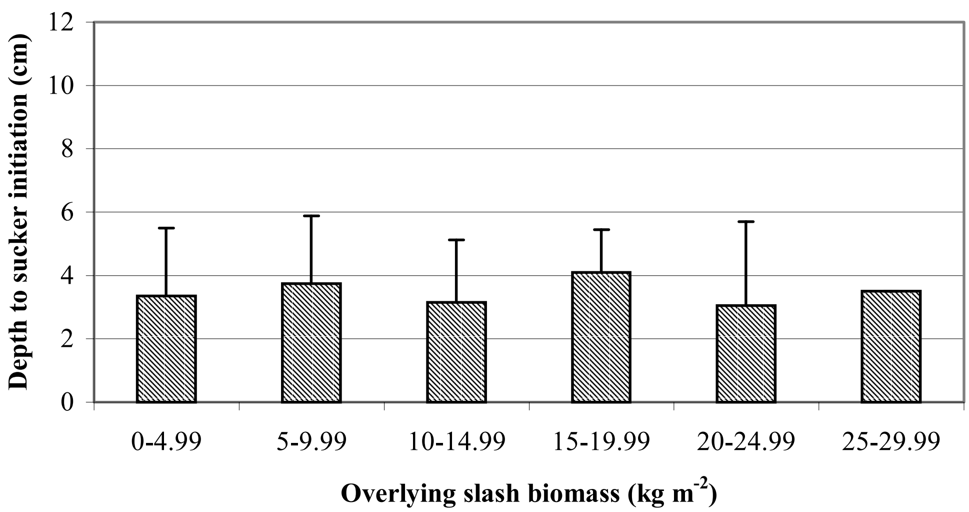

Figure 2. Mean depth of sucker initiation from the parental root to the soil surface of aspen suckers excavated from under varying loads of slash in summer cutblocks.

Impact of Slash Loading on Soil Temperature and Aspen Regeneration

Initial analysis of the soil temperature data collected from the Hobo temperature probes indicated that slash load does indeed have a significant effect on soil temperature. At the LFH-mineral soil interface, daily mean soil temperatures during the growing season were lower under heavy slash loads than under no slash load. The soil temperatures from the probe located 10 cm below the LFH-mineral soil interface appeared to exhibit similar trends as those seen from the probe located at the LFH-mineral soil interface. Although these trends are similar, there is less variation in daily mean soil temperature at 10 cm below the LFH-mineral soil interface as compared to those exhibited at the LFH-mineral soil interface. Because the examination of the pattern of sucker initiation indicated that the majority of aspen suckering seems to be occurring within the LFH layer, only the temperature data from the LFH-mineral soil interface will be presented in this report.

Daily mean soil temperature profiles

During the first growing season daily mean soil temperatures were calculated for each of the 18 probes in the winter and summer cutblocks. The visually chosen slash categories were lighter in the summer cutblocks than in the winter cutblocks: the moderate slash load in the winter cutblocks had a biomass of 5 - 30 kg m^{-2} (mean = 11.6 kg m^{-2}) while the moderate slash load in the summer cutblocks had a biomass of 5 - 15 kg m^{-2} (mean = 7.3 kg m^{-2}), the high slash in the winter cutblocks had a biomass of 30 – 110 kg m^{-2} (mean = 57.6 kg m^{-2}) while the high slash load in the summer cutblocks had a biomass of only 15 – 30 kg m^{-2} (mean = 21.5 kg m^{-2}). As the summer cutblocks were harvested in mid-July, they had a shorter first growing season than the winter cutblocks. The daily mean soil temperatures were summarized monthly by slash load category in order for ease of comparison.

Examination of the daily mean soil temperatures at the LFH-mineral soil interface during the first growing season indicated that soil temperatures were significantly lower under heavier loads of slash in both the winter and summer cutblocks (Figure 3, Figure 4). In the winter cutblocks mean daily soil temperatures over the entire first growing season (May to September) decreased significantly under moderate slash loads and decreased further under the high slash load. In the winter cutblocks, the difference in soil temperatures between the different slash categories is most pronounced in the early part of the growing season (May and June). This is likely due to the lack of vegetation cover during the early part of the growing season. Increased exposure results in more extreme temperature conditions. Vegetation cover and litter can effectively delay spring thaw and decrease summer soil temperatures (Hogg and Lieffers 1991). In the summer cutblocks, the mean daily soil temperature over the entire first growing season (July to September) decreased significantly under moderate and heavy slash loads as compared to under no slash load. However, there were no significant differences between soil temperatures found under moderate and heavy slash loads.

During the second growing season, daily mean soil temperatures were calculated for each of the 18 probes in the winter cutblocks and for each of the 24 probes in the summer cutblocks. In the summer cutblocks the very heavy slash load category was monitored only during the second growing season and second winter season. The very heavy slash load in the summer cutblocks had a biomass range of 30 – 80 kg m^{-2} and a mean value of 51.7 kg m^{-2}.

Similar trends in soil temperatures occurred during the second growing season as those seen in the first growing season. Again in both the winter and summer cutblocks, an increase in slash load resulted in significantly lower soil temperatures (Figure 5, Figure 6). In the winter cutblocks, the differences in soil temperature were not as distinct as they were in the first growing season. In fact, the overall growing season temperatures indicated that there were no differences in soil temperature between no slash load and a moderate slash load in the winter cutblocks. This decrease in the clarity of the temperature trend is likely a result of a combination of factors, such as the increasing establishment of surrounding vegetation and the gradual decay of the slash load over time. In summer cutblocks, again there was a significant decrease in soil temperatures with increasing slash loads during the entire second growing season. And, as before, there was no significant difference in soil temperatures between the moderate and high slash loads. The very high slash load, however, did result in significantly lower soil temperatures than the no slash load, the moderate slash load and the high slash load. Significant differences in soil temperatures under the different slash loads throughout the second growing season in the summer cutblocks may be due to the fact that the first growing season was so short and the surrounding vegetation has not had a chance to become so firmly established as in the winter cutblocks.

Winter season soil temperatures generally have little effect on aspen growth unless they reach extremely low temperatures harmful to plant material. Aspen root growth may be limited or even stopped when exposed to extremely high or low soil temperatures. During the first winter season, daily mean soil temperatures were calculated for each of the 18 probes in the winter cutblocks and for each of the 18 probes in the summer cutblocks. During the second winter season, daily mean soil temperatures were calculated for each of the 18 probes in the winter cutblocks and for each of the 24 probes in the summer cutblocks. In both the first and second winter seasons, there were some significant differences in soil temperatures under the different slash loads but few obvious trends (Figure 7, Figure 8, Figure 9, Figure 10). The mean daily soil temperatures did not reach extremely cold temperatures during the first or the second winter season. During the spring, the soil temperatures were significantly warmer under the no slash load in both the winter and summer cutblocks and during both the first and second winter season.

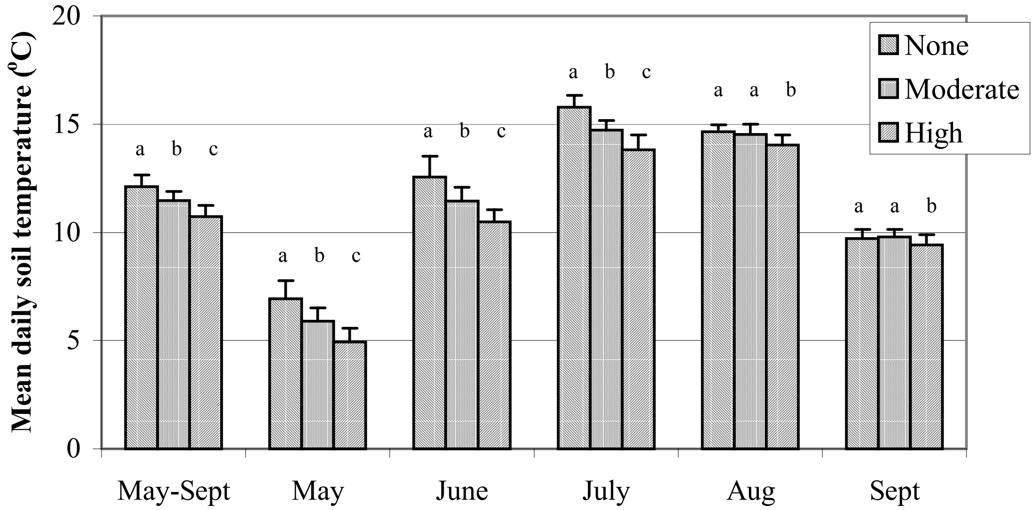

Figure 3. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the first growing season.

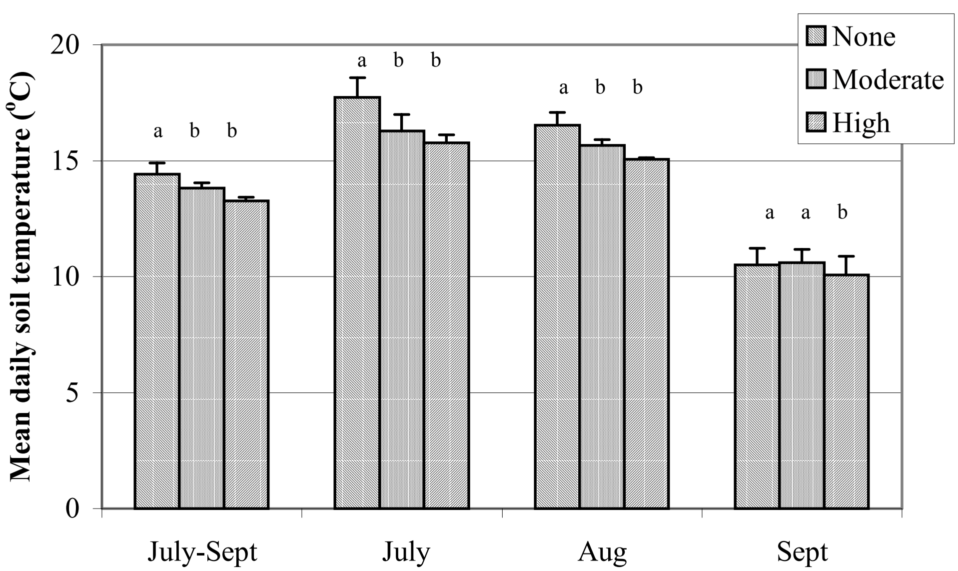

Figure 4. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the first growing season.

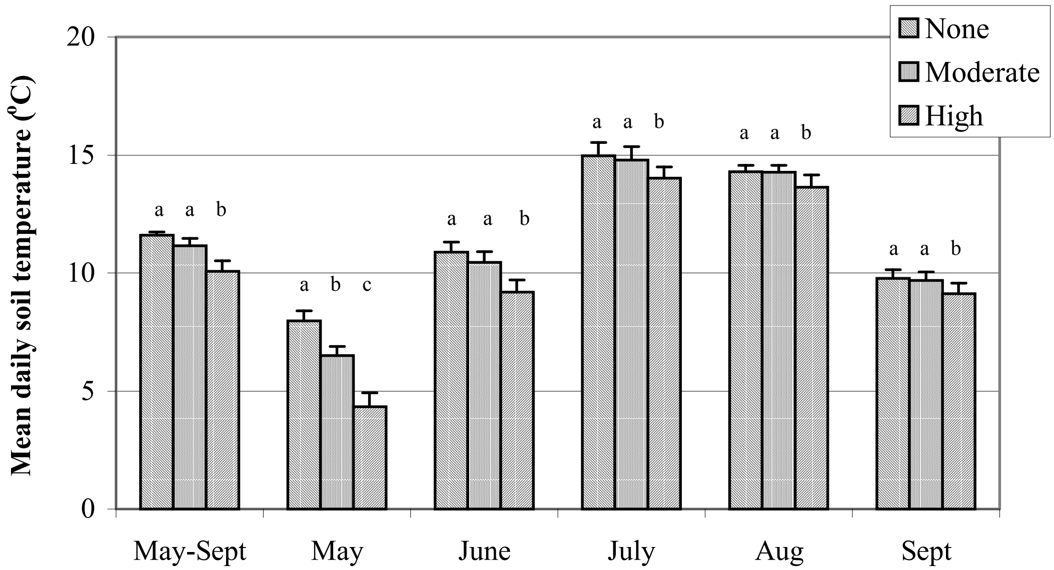

Figure 5. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the second growing season.

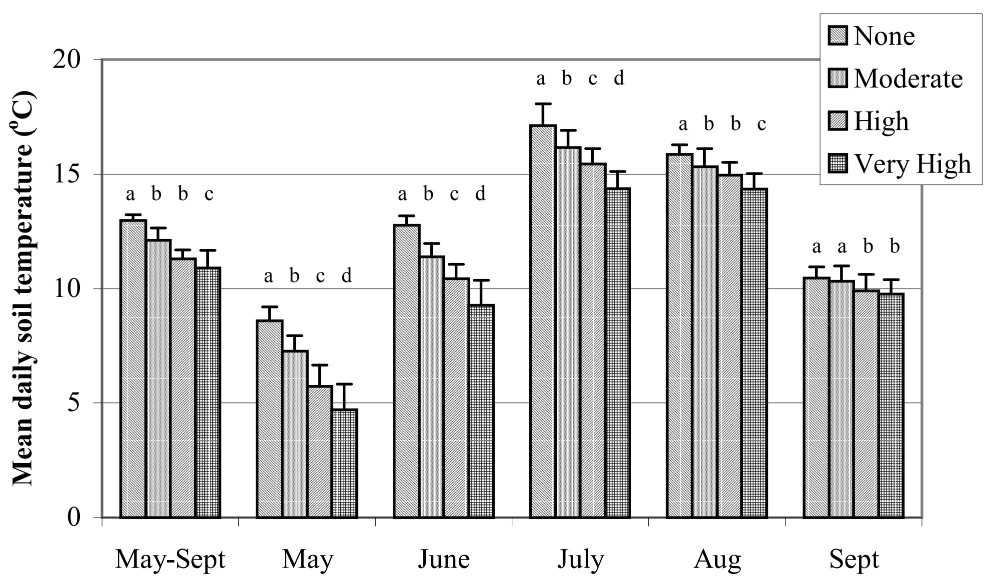

Figure 6. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the second growing season.

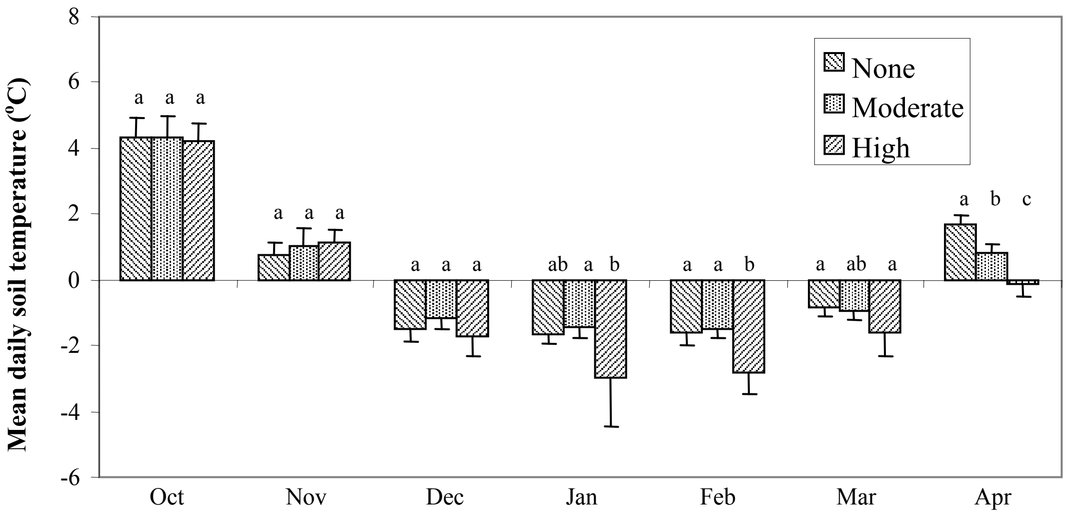

Figure 7. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the first winter season.

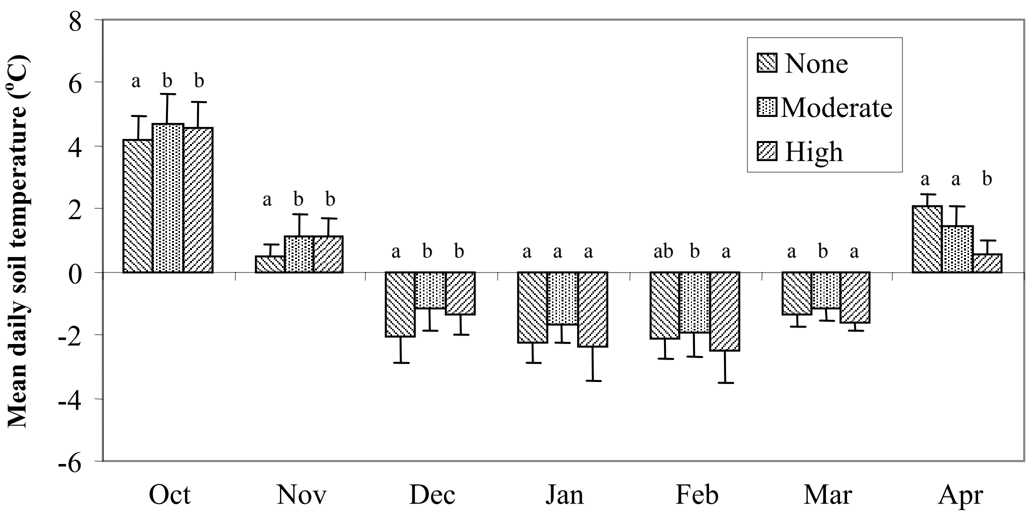

Figure 8. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the first winter season.

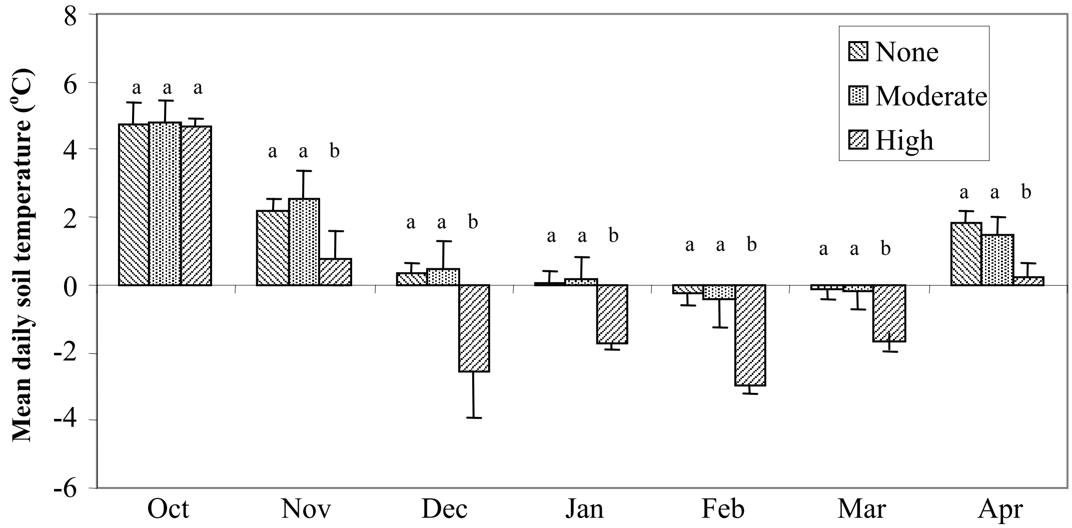

Figure 9. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in winter cutblocks during the second winter season.

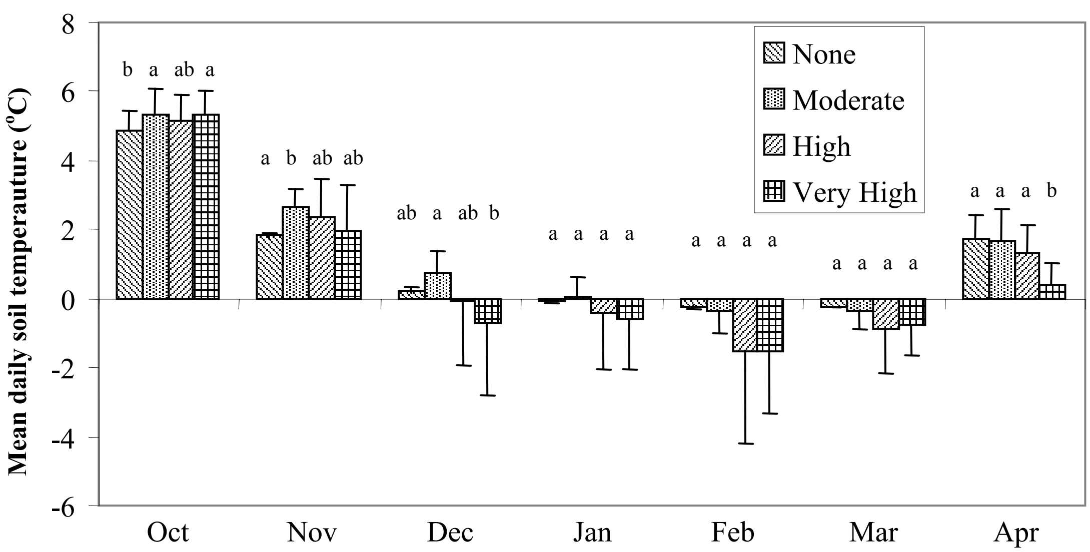

Figure 10. Mean daily soil temperature (LFH-mineral soil interface) under varying slash loads in summer cutblocks during the second winter season.

Date of first frost and spring thaw

Not only do slash loads effectively intercept a large part of the radiation normally captured by the soil, they also decrease the flow of radiative heat into and out of the soil. This results in reduced soil temperatures during the summer and may also affect the length of the growing season by delaying spring thaw. Slash residues may delay spring thaw similarly to the vegetation cover and litter studied by Hogg and Lieffers (1990). A significant delay in spring thaw or an early fall frost results in a shorter growing season for newly established suckers in cutblocks.

In the winter cutblocks during the first growing season, those areas under lower slash loads reached freezing soil temperatures before those areas under high slash loads (Table 3). However, high slash loads resulted in the spring thaw occurring significantly later in the year than those areas under moderate slash load or no slash load. In total, those areas under lower slash loads had fewer total days where the soil temperature was below freezing. During the second growing season, similar trends were noted however differences were not significant.

Table 3. Effect of slash load on length of the winter season in the winter cutblocks (soil temperatures at the LFH-mineral soil interface)

	Slash Load	**Days less than 0 ^{o}C**	**First frost**	**Spring thaw**
First winter season	None	136.17 a	November 17 a	March 18 a
	Moderate	146.00 ab	November 18 a	April 8 b
	High	149.40 b	November 21 b	April 13 c
Second winter season	None	138.83 a	November 17 a	March 22 ab
	Moderate	131.00 a	November 23 b	March 16 a
	High	145.33 a	November 23 b	April 11 b

In the summer cutblocks during the first growing season, those areas under lower slash loads froze earlier in the year, thawed later in the year and appeared to have fewer total days where the soil reached freezing temperatures (Table 4). During the second growing season, again, similar trends were observed; however, differences were not significant.

Table 4. Effect of slash load on length of the winter season in the summer cutblocks (soil temperatures at the LFH-mineral soil interface)

	Slash Load	**Days less than 0 ^{o}C**	**First frost**	**Spring thaw**
First winter season	None	76.20 a	January 12 a	April 7 a
	Moderate	88.67 a	December 2 a	April 20 a
	High	165.00 a	November 18 a	April 24 a
Second winter season	None			
	Moderate	68.75 a	January 26 b	April 5 a
	High	81.00 a	January 10 a	April 7 a
	Very High	113.83 a	December 2 a	April 24 a

Growing degree days

To better examine the length of the growing season and in order to provide a comparison between the growing season of those areas under no slash, moderate slash and heavy slash, growing degree days were calculated. Since aspen suckering appears to be inhibited at temperatures less than 15 ^{o}C, this number was used as the base value in the calculation of growing degree days (Navratil 1991; Maini and Horton 1966). By choosing 15 ^{o}C as the base value, this growing degree day calculation should effectively be a measure of the amount of time during the growing season where soil temperatures did not inhibit aspen sucker growth.

In the winter cutblocks, during the first growing season, the growing degree days were significantly lower under high and moderate slash loads compared to those with no slash (Table 5). As was seen in the daily average temperature trends, by the time the second growing season was reached, there was no significant effect on growing degree days. In the summer cutblocks, there was a significant decrease on growing degree days associated with moderate, high and very high slash loads during both the first and second growing seasons (Table 6). In the summer cutblocks, there was no difference in growing degree days between the moderate and the high slash load treatment.

Table 5. Growing degree days (15 ^{o}C) at the LFH-mineral soil interface in winter cutblocks (α=0.05)

	Growing Degree Days	
Slash Load	**First Growing Season**	**Second Growing Season**
None	54.607 a	38.132 a
Moderate	31.176 b	35.739 a
High	11.613 b	18.754 a

Table 6. Growing degree days (15 ^{o}C) at the LFH-mineral soil interface in summer cutblocks (α=0.05)

	Growing Degree Days	
Slash Load	**First Growing Season**	**Second Growing Season**
None	94.400 a	131.28 a
Moderate	50.376 b	68.79 b
High	34.360 b	62.95 b
Very High		26.13 c

Number of hours each day where soil temperature is above 15°C

Increased levels of slash loading resulted in a significant decrease in the number of hours each day where the soil temperature reached 15 °C in both the winter (Table 7) and summer cutblocks (Table 8). These differences are accentuated during June, July and August. As well, June, July, and August were the three months during the growing season which seemed to consistently have a substantial number of hours where soil temperature was above 15 °C. The month of July is likely the most influential time for aspen sucker growth as it had the most hours each day where soil temperatures in the rooting zone reached 15°C.

Table 7. Mean number of hours each day where the soil temperature at the LFH-mineral soil interface in winter cutblocks was at least 15 °C during both the first and second growing seasons (α=0.05)

		Mean hours each day where soil temperature > 15 °C				
	Load	**May-99**	**Jun-99**	**Jul-99**	**Aug-99**	**Sep-99**
First Growing Season	None	0.86 a	6.36 a	12.58 a	10.04 a	0.23 a
	Moderate	0.10 b	3.26 b	10.01 b	9.16 a	0.08 a
	High	0.00 b	0.79 c	5.95 c	5.49 b	0.00 a
Second Growing Season	None	0.75 a	1.87 a	11.30 a	9.69 a	1.02 a
	Moderate	0.01 b	1.20 ab	10.97 a	9.64 a	0.44 ab
	High	0.00 b	0.11 b	8.25 b	6.62 b	0.00 b

Table 8. Mean number of hours each day where the soil temperature at the LFH-mineral soil interface in summer cutblocks was at least 15 °C during both the first and second growing seasons (α=0.05)

		Mean hours each day where soil temperature > 15 °C				
	Load	**May-99**	**Jun-99**	**Jul-99**	**Aug-99**	**Sep-99**
First Growing Season	None			19.57 a	15.82 a	0.62 a
	Moderate			16.88 b	13.58 ab	0.42 a
	High			15.77 b	12.50 b	0.13 a
Second Growing Season	None	0.81 a	5.12 a	17.71a	14.85 a	0.85 a
	Moderate	0.34 ab	2.17 b	15.61 b	13.32 a	0.81 a
	High	0.00 b	0.72 c	13.73 b	13.15 a	0.07 bc
	Very High	0.00 b	0.07 c	9.34 c	9.40 b	0.00 c

Aspen regeneration

Increased slash loads had a significantly negative effect on the number of suckers produced, the leaf area index (LAI) and the total sucker volume for both the winter and the summer cutblocks (Table 9, Table 10). The average number of suckers decreased from 15 suckers per m^2 (150, 000 suckers per ha) under no slash load, to 1.4 suckers per m^2 (14,000 suckers per ha) under high slash loads. In the winter cutblocks the LAI and sucker volume also significantly decreased under the high slash load. The moderate slash load however, did not have a significantly different effect on LAI and sucker volume compared to those under the no slash load treatment.

In the summer cutblocks, there was a significant decrease in aspen sucker production under the moderate slash load, the high slash load, and the very high slash load. The average number of suckers decreased from 15 suckers per m^2 (150,000 suckers ha^{-1}) with no slash load, to 1.8 suckers per m^2 (18,000 suckers ha^{-1}) with very high slash loads. LAI and sucker volume also significantly decreased under higher slash loads. The trend for aspen sucker production in summer cutblocks was similar to the trend observed in daily soil temperatures in summer cutblocks. While any amount of slash did have a negative effect on aspen productivity, there was no significant difference in this negative effect between moderate slash loads and high slash loads. Considering that the moderate and high slash load categories in the summer cutblocks were actually lower than those same categories in the winter cutblocks, this suggests that summer cutblocks were more sensitive to the effects of smaller amounts of slash loading both in terms of soil temperatures and aspen productivity.

Steneker (1973) indicated that aspen clones in the Duck Mountain Forest Reserve are approximately 0.2 acres (0.08 ha) in size. This ample system of roots should be able to produce and support a substantial number of aspen suckers after harvest operations. Large lateral root systems can typically support thousands of aspen suckers. Typical stocking density after harvest operations can be higher than 80,000 suckers per ha but varies substantially (Steneker 1976; Huffman et al. 1999). Manitoba's current Forest Renewal Standard for hardwood regeneration requires that after 5 years of growth, acceptable minimum hardwood densities range from 2500 to 6000 stems ha^{-1} (Delaney 1995). However these values cannot be compared with those densities measured in the first year after harvest. Aspen stands are known to reach their peak sucker production usually within two years following harvest operations and self thinning rapidly begins to occur (Peterson and Peterson 1992). According to Bates et al. (1991) and Huffman et al. (1999), 25,000 suckers per ha is an accepted minimal amount of initial sucker production for successful stand regeneration.

Table 9. Sucker regeneration parameters at the end of the second growing season in winter cutblocks (α=0.1)

Slash Load	Number of Suckers (m^{-2})	Leaf Area Index	Mean Sucker Height (cm)	Mean Sucker Rcd (cm)	Sucker volume ($cm^3\ m^{-2}$)
None	15.0 a	1.02 a	81.8 a	0.94 a	292.6 a
Moderate	9.5 b	0.77 a	67.2 ab	0.75 a	214.6 a
High	1.4 c	0.12 b	49.3 b	0.62 a	37.2 b

Table 10. Sucker regeneration parameters at the end of the second growing season in summer cutblocks (α=0.1)

Load	Number of Suckers (m^{-2})	Leaf Area Index	Mean Sucker Height (cm)	Mean Sucker Rcd (cm)	Sucker Volume ($cm^3\ m^{-2}$)
None	15.0 a	0.60 a	45.4 a	0.55 a	52.2 a
Moderate	7.7 b	0.37 ab	39.1 a	0.40 a	19.9 b
High	4.3 b	0.30 ab	39.7 a	0.43 a	12.7 b
Very High	1.8 b	0.11 b	31.9 a	0.38 a	10.4 b

Diurnal temperature fluctuation

Diurnal temperature fluctuations in the field are believed to play a favourable role in sucker initiation. Maini and Horton (1966) showed that aspen had poor suckering potential during hot days and increased suckering potential associated with cool nights. Zasada and Schier (1973) also did some preliminary work examining diurnal temperature fluctuations. While Maini and Horton (1966) found that temperatures above 23 ^{o}C were inhibitory to aspen suckering if they are held constant, Zasada and Schier showed that if a diurnal fluctuation occurs (25 ^{o}C / 15 ^{o}C), these temperatures were no longer restrictive to aspen sucker growth.

Slash, a highly insulative material, may significantly alter the diurnal temperature cycles in cutblocks and thus may alter aspen suckering. Since increased amounts of slash dampen the diurnal fluctuation in soil temperatures, this may be in part responsible for the decreased sucker production associated with increased slash loading.

Table 11 indicates that with a daily mean of 15 ^{o}C, diurnal temperature fluctuations of 1.5 ^{o}C and 3.5 ^{o}C did not significantly effect sucker production. It may be that while 15 ^{o}C is the minimum temperature where aspen sucker initiation and growth can begin to occur, this temperature is simply not high enough to produce enough biomass to notice any significant differences between aspen suckers (note the very small dry mass of suckers in Table 11).

Table 11. Effect of diurnal temperature variation on sucker production at 15 ^{o}C (α=0.1)

Diurnal Variation (^{o}C)	**Number of suckers**	**Number of sprouts**	**Total suckers and sprouts**	**Mean height (cm)**	**Mean rcd (cm)**	**Mean dry mass (g)**
0	1.5 a	8.6 a	10.1 a	9.2 a	0.34 a	0.041 a
1.5	0.9 a	9.6 a	10.5 a	9.4 a	0.35 a	0.021 a
3.5	1.5 a	12.7 a	14.2 a	9.2 a	0.47 a	0.044 a

MANAGEMENT APPLICATIONS AND CONCLUSIONS

Examination of the pattern of sucker initiation indicated that suckering was consistently occurring at a very shallow depth within the soil profile (<5 cm) and almost exclusively from within the LFH layer. In addition, the suckers more consistently initiated from the top side of the parental root, the area most susceptible to heavy impact. Sucker initiation nearer the soil surface means that the potential for root injury causes increase. Because aspen suckers are initiating near the soil surface simply due to the nature of aspen growth habit in this ecoregion, heavy machine traffic should be monitored closely or should be kept to a minimum during the summer.

Daily mean soil temperature profiles strongly indicated that increased levels of slash loading resulted in decreased soil temperatures especially right after harvest and during the early growing season. Analysis of the first date of fall frost, the spring thaw, length of the winter season and the growing degree days also indicated that not only does an increased slash load result in lower daily mean soil temperatures, it also results in a shorter growing season for those suckers under the heavier slash loads. As decreased soil temperatures and decreased growing season lengths have significant implications for aspen growth, harvest operations should try to avoid leaving large areas with high amounts of slash loads in order to ensure optimal soil temperature conditions for aspen regeneration.

Although the greatest differences in soil temperatures were seen in May, July seems to be the month during which the majority of aspen growth is likely to occur. In both the winter and summer cutblocks during the month of July, increased levels of slash loading resulted in a significant decrease in the amount of hours each day that soil temperature was above 15 ^{o}C. During the month of July, soil temperatures were consistently warm enough to encourage sucker growth.

The analysis of the effects of slash loads on sucker regeneration produced extremely interesting results. Navratil (1996) and Bella (1986) indicated that the amounts of suckers produced under conditions of heavy slash loading substantially decreases. Bella (1986) demonstrated that slash cover on Chernozem soils in Saskatchewan reduced both aspen regeneration and growth. However, no quantitative description of the amounts of slash cover is given and the specific effects of slash loading on soil temperatures were not considered. In this study, in summer cutblocks, moderate levels of slash do indeed severely limit aspen sucker growth and production while in winter cutblocks high levels of slash loading were capable of severely limiting aspen sucker growth and production. Increased slash loads resulted in quantified decreases in soil temperature which affected the number of aspen suckers and their growth.

Interestingly, the effects of slash loading on aspen regeneration also mirrored those effects noted for soil temperature. The trend for aspen sucker production in summer cutblocks was similar to the trend observed in daily soil temperatures in summer cutblocks. While any amount of slash does have a negative effect, there was no significant decrease in aspen regeneration between moderate slash loads and high slash loads. Since the moderate and high slash loads in the summer cutblocks were lower than those in the winter cutblocks, this suggests that either the aspen suckers in the summer cutblocks are more sensitive to the effects of slash loading on soil temperatures or that the summer cut methods differed from the winter cut methods in some way which correlated with the slash left on the cutblock. Apparently, it is essential to be especially cautious with the amount and distribution of slash left in summer cutblocks by harvest operations. In order to ensure successful aspen regeneration, it may be necessary to make an improved effort to distribute slash evenly within summer cutblocks.

The effects of slash loading on both soil temperature and aspen regeneration must be considered in terms of its relative importance at a field scale level. The potential negative effects of high levels of slash loading are only of importance if there is an incidence of high levels of slash normally found in cutblocks. Using the two slash estimation methods allowed for the estimation of the mean amount of slash in both winter and summer cutblocks. In both the winter and the summer cutblocks the mean amount of slash most often fell within the "moderate slash" loading category. In winter cutblocks, the mean amount of slash would likely have a very small if any impact at all on aspen regeneration. However, as previously noted, 14% of the area measured had slash which fell into the heavy category. Aspen growing under these conditions are likely to encounter a decrease in productivity. In the summer cutblocks, the mean amount of slash was described as a moderate amount of slash. Moderate slash loads do significantly decrease soil temperatures and aspen regeneration in summer cutblocks. These moderate amounts of slash will likely result in a significant decrease in aspen suckering capability on a larger scale in the summer cutblocks. Additionally, 11% of the sampled area in the summer cutblocks fell into the heavy category and would most likely result in a measurable decrease in aspen suckering success.

It may be argued that the number of suckers produced under high slash loads was still near the minimal amount of suckers necessary for successful regeneration. However, this negative effect on aspen is extremely important since early sucker growth is believed to be necessary to maintain the parental root system (Desrochers 2000). Until suckers have developed their own root systems, they depend on the parental root system for moisture and nutrients, thus it is important and necessary to maintain a healthy parental root system in order to have successful long term aspen suckering. These parental root systems initially provide the essentials for sucker growth but suckers must in turn provide carbohydrates necessary to maintain the healthy rooting system. Although sucker density standards are quite low, it may in fact be necessary to establish a higher density of aspen suckers in the first few years of forest regeneration in order to ensure that the parental root system is maintained. Distributing slash more evenly in cutblocks may decrease this negative effect on aspen suckers and aspen root systems. Harvest operations should avoid producing areas of very dense slash to ensure that healthy aspen root systems are able to sustain mature, fully stocked stands.

Perhaps further investigation of slash loading in cutblocks will be able to elucidate optimal or maximal levels of slash distribution for successful aspen regeneration. In order to reinforce the importance of slash distribution on a cutblock level, a visual slash loading guide was produced. Ideally, this was meant to be a visual estimation system developed for machine operators in order to ensure full stand regeneration.

Soil temperature is a factor which has a strong influence on root growth, root development, and ultimately aspen sucker productivity. Knowledge about this subject, is critical to implement management applications which will ensure long-term forest sustainability. Hopefully by using the information gained in the study, analysis, and the visual slash loading guide, the ecology of trembling aspen and factors affecting stand re-establishment will be better understood.

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