Field Measurement of Photosynthetically Active Radiation[1]

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Abstract.--Site preparation treatments reducing competing vegetation achieved adequate light levels for white spruce photosynthesis but did not alleviate limiting root zone soil temperature. Mechanical treatments which disturb site humus layers increased both light availability and soil temperature and resulted in increased growth performance over a 5 year period. Increased depth of mineral capping on inverted organic mounds significantly increased seedling growth performance.

INTRODUCTION

Intensity of radiation exerts a direct effect upon plant photosynthesis and morphogenesis, and an indirect effect due to environmental heating. In selecting site preparation treatments it is important to identify factors limiting growth on the site (Cleary and Kelpsas 1981, Draper 1982), and to assess the extent to which the treatment has been successful in reducing these biological stresses. On sites with well developed competitive vegetation, the relative importance of increased radiation to the seedling for driving the light reaction in photosynthesis, and the role of radiation in increased environmental heating, following a site preparation treatment, is often unclear. Field investigations are seldom able to separate the combined effect of most site preparation treatments. However, an understanding of this is important in developing and selecting treatments which promote seedling survival and growth in the regeneration time frame.

In this study the direct effects of site preparation treatment on photosynthetically active radiation ([PAR], 400 - 700 nm wavelengths) at seedling height was measured for two growing seasons following treatment, and interpreted in terms of light compensation and saturation thresholds determined for spruce (*Picea glauca* (Moench) Voss) seedlings in the field. Subsequent five year seedling height and ground-line diameter growth data are also presented for these treatments. The short term response of radiation and soil temperature to serial vegetation clipping, and combined vegetation and organic layer removal to mineral soil, are presented for the same site. Comparative soil temperature data from a wide range of site preparation strategies on adjacent sites are presented as welt.

SITE DESCRIPTION

A north-east aspect, slope of the Bowron River Valley (Lat. 53° 40' N, Long. 121° 40' W) in the central interior of British Columbia was selected for study. The site is within the Rocky Mountain Subzone (f) of the sub boreal spruce zone'. Prior to treatment, abundant herb and brush species (0.85 - 1.20 m average height) combined to present severe vegetation competition. Soils on the site are gleyed, grey luvisols (Can. Soil Survey Com. 1978) characterized by mottling. The area's continental climate (mean January and July air temperatures -12 and 15° C, respectively) and site history under a 200-300 year-old mature spruce and alpine fir forest canopy, have resulted in development of a thick (0.10 - 0.25 m) mor humus layer. This organic layer remained largely undisturbed following winter logging in 1982.

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SITE PREPARATION AND PLANTING

A Bracke cultivator equipped with Robur Maskin A-B's Hoglaggare mounding attachment behind a D7E prime mover was used to create inverted organic mats in August 1983. The mounder shovels were disengaged throughout, resulting in inversion of 0.3 by 0.4 m patches of consolidated organic material over undisturbed organic material. Manual additions of 0.0, 0.06, 0.12 and 0.24 m depth cappings of B horizon mineral soil were carried out to create a depth of capping range referred to as the organic mat and mineral mound treatments, respectively. Control (not mechanically prepared) areas were also established as part of the trial design. Bare root 2+1 white spruce (B.C. Forest Service Registered Seedlot 4093) were planted on all site preparation treatments between May 30 and June 15, 1984. Seedlings were centered on prepared organic mats and mounds, and planted within a screef to mineral soil on the control treatment.

A wide range of site preparation treatments were established on adjacent areas for further comparison. These were an operational prescribed fire treatment (burned August 1983); a broadcast herbicide application (0.8 m radius plot, Roundup [glyphosatel at 2.25 kg a.i.•ha^{-1} on August 5, 1983); a blade scarification treatment (organic layers scalped to bare mineral soil on August 1983); and, broadcast herbicide treatment combined with inverted organic, mineral mounds (0.30 m depth of capping an inverted organic patches in August 1983).

MEASUREMENTS

Measurements were made of diurnal PAR patterns on 5 replicates of seedling pairs (control and 0.24 m mound treatment, 1984) and triplets (control, organic mat, and 0.24 m mounds, 1985) using Li-Cor 190SB cosine corrected quantum sensors, interrogated every 60 seconds and integrated and recorded every 30 minutes. Treatment sensors were levelled at *predetermined* mean seedling height of 0.36 m (1984) and 0.44 m (1985), while a background sensor was maintained above competing vegetation (1.5 m). The replicate pairs or triplets were sampled sequentially (between July 18 and October 16, 1984, and June 9 and September 17, 1985) in 14-21 day cycles to provide treatment averages. Background and treatment sensor readings were made simultaneously and recorded in NE m^{-m} $s^{-'}$. For comparative purposes, treatment values may be expressed as a percent of background PAR rate or as mean daily radiation totals (μE m^{-m} day^{-1}). Generalized light saturation and light compensation thresholds (600 and 100 NE m^{-m} s^{-}", respectively) were determined for these white spruce seedlings in the field using a Li-6000 portable photosynthesis apparatus (Draper et al. 1985). Mean seedling height and ground-line diameter were measured at time of planting and at the end of the first through fifth growing seasons on all treatments.

A single, 1.26 m radius, clipping plot was established in a representative complex of lady fern, fireweed and false hellebore (0.90 m height) and instrumented with 3 replicated thermistor-type soil temperature sensors (0.05 m depth in mineral soil), and a quantum sensor leveled at 0.15 m at plot centre. In an immediately adjacent area, left untreated, a further 3 soil temperature sensors and a background (1.5 m) PAR sensor were installed. Daily mean, minimum and maximum soil temperatures were calculated from 30 minute averages and recorded. Plot vegetation was serially clipped and removed on August 15, 19, 22 and 27 reducing plot leaf area from 100% to 0%. Clipped leaf area was measured with a Li-Cor 3100 leaf area meter and expressed as a percentage of total plot leaf area. Following removal of all competing vegetation the plot was manually scalped on September 8, to bare the mineral soil surface.

A series of soil temperature sensors were installed in alternative site preparation treatments on site including a control treatment, prescribed fire, blade scarification, organic mat inversion (Bracke patch scarification), mounding treatments with differing levels of capping, broadcast herbicide treatment, and broadcast herbicide in combination with mounding. A manual (1200 - 1400 h) measurement was made of 4 replicate thermistors in the 1985 growing season, and, for comparative purposes the data expressed as a percentage of the measured control treatment temperature.

RESULTS

Figure 1 shows a typical diurnal PAR trace on a clear July day as received above the vegetation (background), and at seedling height in the control and mounded treatments. The mineral mound treatment received nearly all measured background radiation with the exception of low sun-angle periods (0500-0900 and 1700-2100 h PDST). The control treatment trace is strongly affected by vegetation interception, resulting in an irregular sun-fleck pattern over most of the lighted part of the day. Rate of PAR on the mound treatment is nearly that of background at mid-day, but control PAR rate is much *reduced* compared to background.

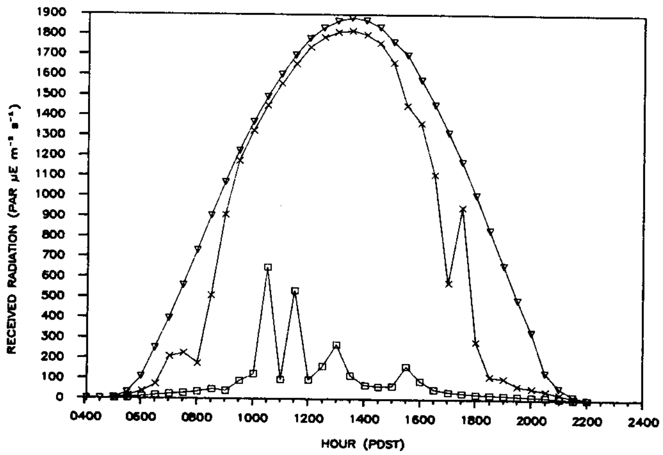

Figure 1.--Typical diurnal PAR pattern on a clear July day in 1984 one year after site preparation. Background sensor above competing vegetation (V) at 1.5 m height, control ([]) a ineral mound treatment (x) sensors at seedling height (0.36 m).

Daily treatment PAR patterns, averaged over the 1984 growing season, are shown in Figure 2 with light compensation and saturation thresholds overlain. Values plotted are the mean half hourly rate of replicated samples between July 18 and October 16, 1984. One year following site preparation, mounded seedlings received approximately 70% of mean total daily radiation (background). The control seedlings averaged 11% of background over the same period. Interpreted in terms of the light thresholds, mounded seedlings received 66% of available PAR between 100 and 600 NE m'- s^{-1} and were above compensation threshold for 10-11 hours a day. Control seedlings, by contrast, averaged 15% of background total radiation between 100 and 600 NE m^{-0} s^{-1}, and exceeded compensation thresholds for only 4-5 hours in the average day (fig. 2).

In the second growing season (1985) a combination of increased mean seedling height and a reduction in average height of competing vegetation changed the relationship of received radiation between treatments. Control, organic mat and mound treatments seasonal mean diurnal patterns are given in Figure 3. Mound treatments received 78%, the organic mat treatment 64% and the control 49% of mean daily background total PAR. Duration of exposure to PAR above compensation threshold was similar for all treatments, averaging 10-11 hours a day. Seedlings planted on organic mats received less total radiation than mounded seedlings, but similar amounts between the 100 and 600 mu E m(-2)s^(-1) thresholds.

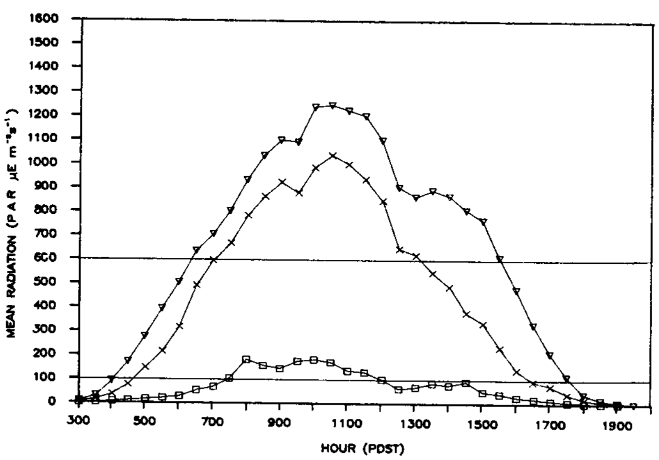

Figure 2.--Treatment mean diurnal PAR pattern during 1984 (July 18-Oct.16) growing season. Background sensor above competing vegetation (V) at 1.5 m, control ([]) and mineral mound treatment (x) sensors at seedling height (0.36 m). 100 and 600 µE m^{-0} s^{-1} light compensation and saturation thresholds, respectively.

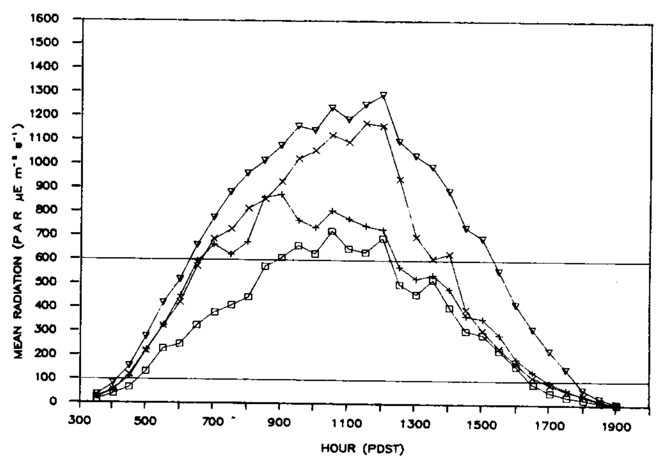

Figure 3.--Treatment mean diurnal PAR pattern during 1985 (June 9-Sept.17) growing season. Background sensor above competing vegetation (V) at 1.5 m, control ([]), inverted organic mat (+) and mineral mound treatment (x) sensors at seedling height (0.44 m). 100 and 600 µE m^{-2} s^{-1} light compensation and saturation thresholds, respectively.

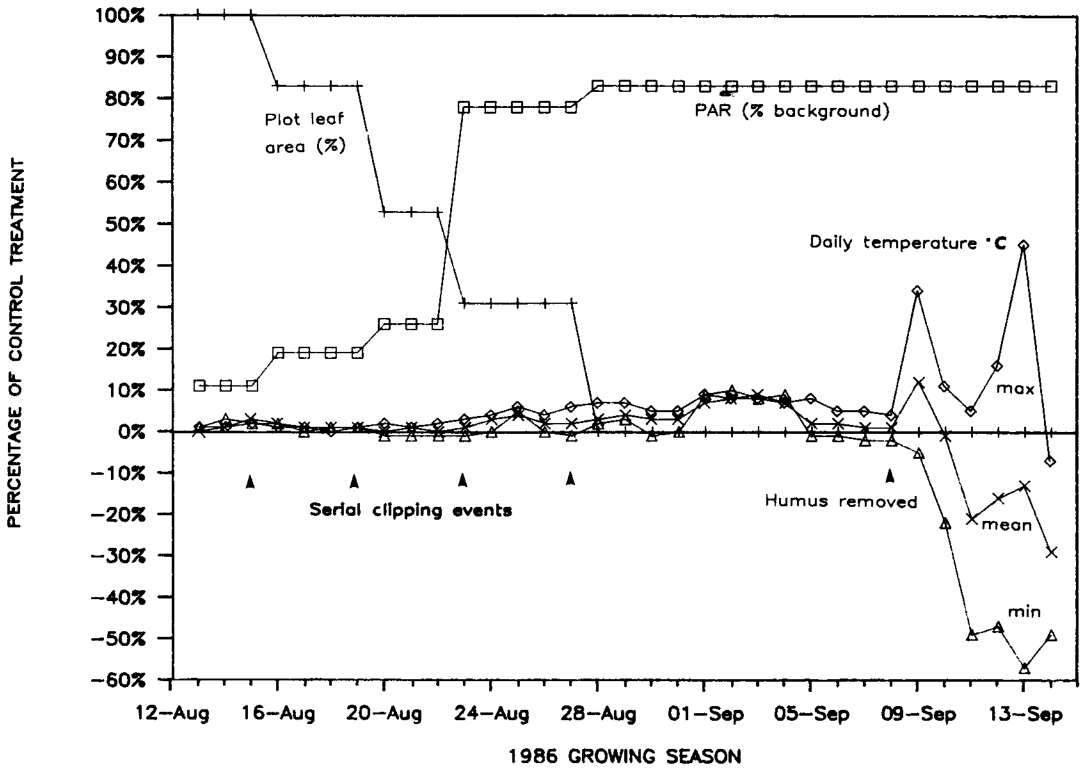

Figure 4.--Short term response of received radiation at seedling height and soil temperature (0.05 m depth) to reductions in vegetative cover. Seedling radiation ([]) expressed as a % of background (1.5 m) radiation, and daily minimum (^), maximum (diamond) and mean (X) mineral soil temperature (0.05 m depth) as a % of control (untreated) soil temperature. Leaf area reductions (+) on August 15, 19, 22, 27 expressed as a % of plot total leaf area.

The effect of incoming PAR on short term soil temperature characteristics was assessed by serially reducing the vegetative cover of a 1.26 m radius plot and measuring changes in received PAR and soil temperature (fig. 4). Prior to first treatment (August 15) radiation beneath the undisturbed competing vegetation canopy averaged 11% of background daily totals. In the same period, daily soil temperature averages in the treatment plot exceeded those of the adjacent control by about 1%, or 0.1° C above the control average of 10° C. PAR response to vegetation removal, averaged over the post clipping period, was immediate (fig. 4). Removal of up to 50% plot leaf area increased received radiation at 0.15 m height from an average of 11% to only 26% of background. The next vegetation removal, from 50% to 30% plot leaf area, resulted in a large increase in received PAR from 26% to 80%. Subsequent removal of the remaining 20% plot leaf area had little effect on received radiation percent (fig. 4). The difference between plot PAR after August 28 (100% leaf area removed) and background PAR is attributed to plot edge effects at low sun angles (see fig.2 and 3).

Daily soil temperature at 0.05 m depth in the mineral soil, beneath a 0.20 m consolidated mor humus, did not respond greatly to level of vegetation clipping, or total vegetation removal (fig. 4) over the period considered. Effects have not been masked by considering average daily mean, minimums and maximums as the half hourly trends collected (not presented) did not show a consistent response to clipping treatments either. Maximum increases in mean daily soil temperature over the 12 day period following vegetation removal were 9%, or less than 1° C, greater than the 10° C control soil temperature recorded (fig. 4), and followed a 4 day period of high radiation.

Scalping the organic layer to expose mineral soil (September 8) had an immediate and relatively large effect on soil temperature (fig.4). Daily mean, maximum and minimum temperatures were directly driven by ambient air temperature (not shown). Scalped plot maximum daily temperatures exceeded control maximums (7.5° C) by 3° C, and minimum temperatures were as much as 4° C below the recorded control daily minimum of 6.5° C.

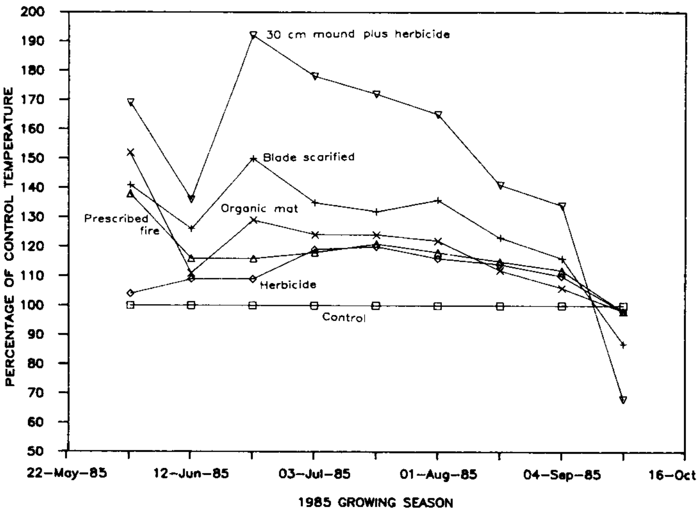

Figure 5.--Mean mineral soil temperature (0.10 m depth) between 1200-1400 h PDST by site preparation treatment over the 1985 growing season. Values expressed as a % of control (untreated) soil temperatures.

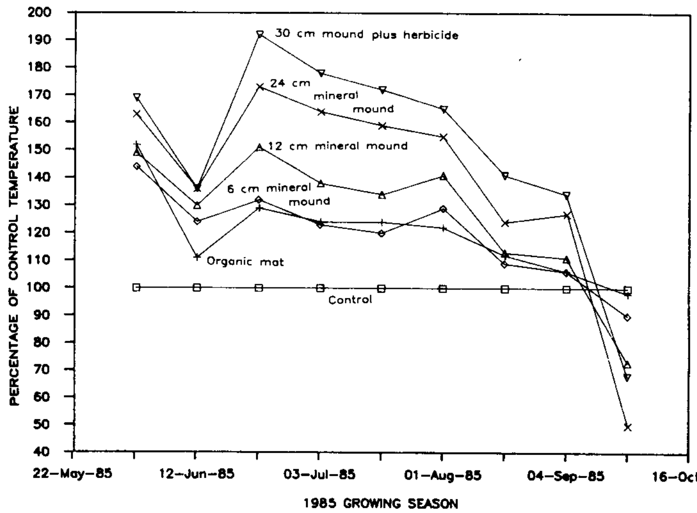

Figure 6.--Mean mineral soil temperature (0.10 m depth) between 1200-1400 h PDST by site preparation treatment over the 1985 growing season. Values are expressed as a % of control (untreated) soil temperatures.

Data presented in Figure 4 is corroborated by the general temperature response measured over a wide range of site preparation treatments. Highest mid-day mineral soil temperatures (0.10 m depth) were recorded on site preparation treatments which remove or invert the organic layer (fig. 5). Neither prescribed fire treatment (which blackened and reduced but did not totally consume the organic layer), or the herbicide treatment (which effectively controlled competing vegetation to less than 30% total cover) were as effective at increasing mid-day soil temperatures as mechanical treatments. Within the range of inverted organic mat and mounding treatments tested (fig. 6) there was a consistent increase in soil temperature associated with increased depth of mineral capping. Seasonal average control temperatures in Figure 6 ranged from 6° C in late May to 10° C in August. Large mineral mound soil mid-day temperature averaged 15° C over the same period. Reduction of the vegetative competition remaining after mounding by herbicide application further increased measured soil temperature as shown by the mounding plus herbicide treatment (fig. 6).

Increased depth of mineral capping on inverted organic mats resulted in increased soil temperatures and subsequent improvement in seedling growth (figs. 7 and 8). The trend to increased total height and ground line diameter with increased depth of mineral capping is consistent, and the fifth year treatment means are significantly different statistically. This corroborates observations made by McMinnb regarding growth performance of spruce seedlings on inverted organic mounds with differing levels of capping.

DISCUSSION

On sites with continuous, well developed organic layers site preparation should be targeted at reduction, mixing or inversion of the organic material to increase root zone soil temperatures rather than vegetation reduction to increase available light. Mechanical treatments which remove or disturb the insulating organic layers are associated both with increases in soil temperature (McMinn 1982) and adequate PAR for_ photosynthesis (fig. 3). Removal of vegetation alone, on sites with relatively thin humus, may result in increased soil temperature', but more generally, soil temperatures in the sub boreal spruce zone are too low for maximum root growth even following clear cutting (Dobbs and McMinn 1977, Draper et al. 1985).

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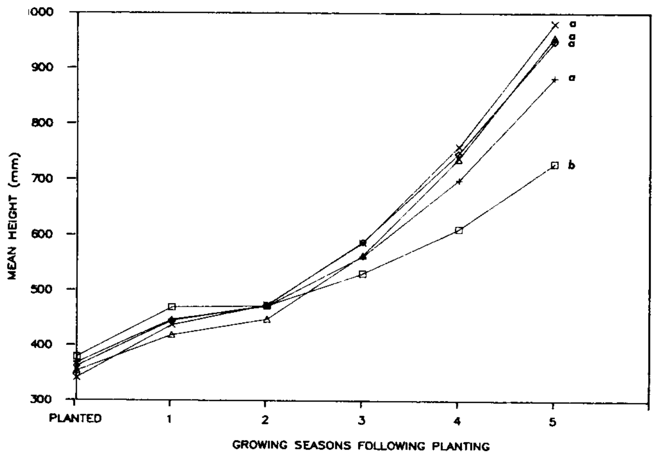

Figure 7.--Treatment mean seedling height (m) at time of planting and following 1 - 5 field growing seasons. Values plotted are the means of approximately 135 seedlings. Control (□), inverted organic mat (mat) (+), mat plus 6 cm mineral capping (◇), mat plus 12 cm mineral capping (△), organic mat plus 24 cm mineral capping (X). Fifth year treatment values followed by the same letter are not significantly different by Duncans multiple range test at alpha = 0.05.

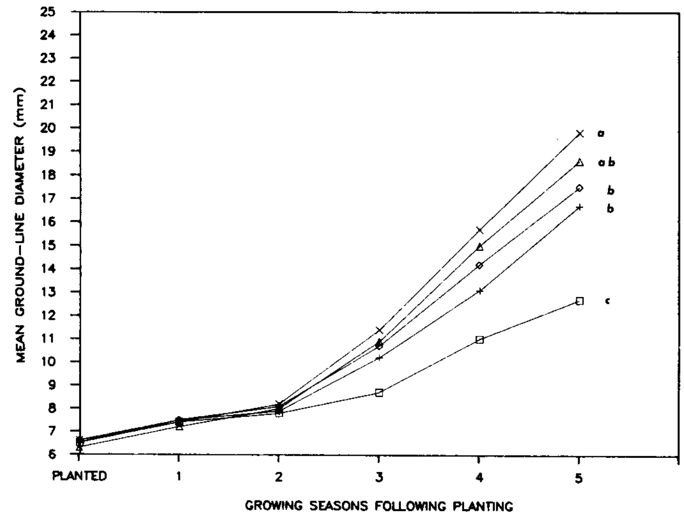

Figure 8.--Treatment mean seedling ground-line diameter (mm) at time of planting and following 1 - 5 field growing seasons. Values plotted are the means of approximately 135 seedlings. Legend as in fig. 7. Fifth year treatment values followed by the same letter are not significantly different by Duncans multiple range test at alpha = 0.05.

Removal of half the leaf area of a 100% cover lady fern association increased received radiation at seedling level from 11% to only 25% of the above canopy background. Significant radiation increases, to well over seedling saturation thresholds, were measured with removal of about 70% of plot leaf area. The advantages of further vegetation reduction are slight in terms of radiation required to drive photosynthesis and measured increased mineral soil temperature (fig. 4) unless the in situ humus is disturbed.

CONCLUSIONS

Identification of the specific biological limitations to seedling growth under field conditions is very difficult, both empirically and experimentally. The relationships of measured light and soil temperature availability to planted seedlings, in response to site preparation strategies, suggest that soil temperatures rather than available light is limiting in the area of the sub boreal spruce zone considered in this experiment. Operational site preparation treatments targeted on organic layer removal or inversion provide both increased soil temperature and, at least temporarily, reductions in competitive vegetation, which result in above average fifth year seedling growth.

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