Effects of shelterwood and site preparation on microclimate and establishment of white spruce seedlings in boreal mixedwood forests

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Abstract

Microclimate and seedling performance of planted white spruce were investigated under canopy and site preparation treatments in an aspen-dominated site in central Alberta. The partial canopy of the shelterwoods had a less extreme environment than the clearcut; higher humidity and soil temperature; lower maximum air temperature and occurrence and severity of night frost; and a light regime that was nearly optimum for height growth of juvenile white spruce. Planted white spruce seedlings had earlier bud break, lower seedling mortality and terminal bud mortality, higher rates of photosynthesis and stomatal conductance, and greater height and diameter increments under shelterwoods than those in either clearcut or control. Site preparation increased soil temperature, decreased seedling mortality and improved growth, especially diameter growth. This study demonstrates how shelterwoods and site preparation can improve the establishment of white spruce.

Key words: Shelterwood; site preparation; white spruce; seedling performance; microclimates.

Introduction

The slow growth of planted seedlings in the first few years after planting, commonly referred to as planting check, has been widely reported for white spruce (Picea glauca (Moench) Voss) plantations (Vyse 1981; Burdett et al. 1984; Mullin 1963; Nienstadt and Zasada 1990). At minimum, this slow growth can cause the loss of several growing seasons, but in many cases it can result in plantation failure if heavy beds of vegetation establish quickly and overtop the trees (Eis 1981). Suggested causes for the poor initial establishment of white spruce include excess or deficient soil moisture, excess solar radiation and day time temperature, summer frosts, low soil temperature, and nutrient deficiency (Mullin 1963; Burdett et al. 1984). Some studies suggest that water stress resulting from low soil moisture and temperature and a high vapour pressure deficit is the primary causal factor (Grossnickle 1988; Marsden et al. 1996) limiting the ability of newly planted seedlings to absorb water from soil (Burdett 1990).

Regeneration conditions can be improved by manipulating the forest canopy and ground surface. In shelterwood systems, the old stand is gradually removed while simultaneously establishing the next stand of trees under old trees (Smith 1986) so that the shelterwood retains some characteristics of understory conditions: cooler daytime temperature, higher relative humidity and lower VPD, lower frequency and severity of night frosts, and less intense irradiance compared to open environments (Childs and Flint1987; Man and Lieffers 1997). A typical shelterwood system includes preparatory, seeding and removal cuts (Smith 1986), but a two-cut uniform shelterwood system combining preparatory and seeding cuts is most commonly applied (Hannah 1988; Waldron and Kolabinski 1994). At the ground level, environmental conditions of the planting sites can be modified by site preparation (Örlander et al. 1990; Spittlehouse and Childs 1992; Munson et al. 1993). In boreal mixedwood forests, mechanical site preparation such as trenching, blading, ploughing., mixing or mounding, are commonly used to reduce competition, raise soil temperature and perhaps stimulate mineralization of nutrients (Lieffers and Beck 1994).

There have been several attempts to apply shelterwood systems and mechanical site preparation to regenerate white spruce in boreal mixedwood forests (Waldron 1959; Lees 1962, 1963, 1970ab; Youngblood and Zasada. 1991) and satisfactory regeneration of white spruce has been produced in white spruce-dominated forests (Waldron and Kolabinski 1994). These shelterwood cuts, however, relied on natural regeneration and lacked thorough investigations of the environmental conditions. How different levels of residual density of shelterwood and methods of site preparation affect the environmental conditions and establishment of planted white spruce is not yet clear.

This study examines the effects of different levels of residual density of the canopy and site preparation on such environmental components as light availability (transmission of photosynthetic photon flux density through the overstory canopy) and light quality (Red:Far Red ratio), air temperature and frost occurrence, relative humidity, and soil temperature. The study also investigates budflush, mortality, photosynthesis and growth of white spruce seedlings in the early period of establishment after planting.

Materials and Methods

Site Description

The study was located in a boreal mixedwood site, 65 km northwest of Edson, Alberta, Canada (53°42' N, 117° 05' W), with an average slope of about 5% and an average elevation about 1050 m above sea level. Climate is subhumid and continental, with long, cold winters and mild summers. Data from the closest weather station (Edson, Alberta) indicate a mean annual precipitation of 568 mm, mean annual temperature of 1.8 °C, mean temperature of -11.8 °C for the coldest month and 14.8 °C for the warmest month (Environment Canada 1996). The dominant soil type is a Brunisolic Gray Luvisol developed in a thin veneer of loam to sandy loam textured fluvial sediments, underlain by clay loam to clay textured morainal parent material (Proudfoot 1994). Soil pH ranges from neutral to slightly alkaline (6.5 to 8.0). The organic layer is about 8 cm. Surface drainage is generally good; internal drainage, however, may be somewhat impeded by abrupt textural changes.

Prior to the cutting treatment, the site was covered by a 120-year-old mature aspen-white spruce mixedwood, approximately 15-25 m^2/ha basal area (BA) in aspen (Populus tremuloides Michx.) and 7-15 m^2/ha BA in white spruce with a small amount of balsam poplar (Populus balsamifera L.), black spruce (Picea mariana (Mill.) B.S.P.) and lodgepole pine (Pinus contorta var. latifolia Engelm.). The shrub layer in the control conditions was composed mainly of Rosa acicularis Lindl. and Viburnum edule (Michx.) Raf. Major herbaceous species were Aralia nudicaulis L., Cornus canadensis L., Epilobium angustifolium L., Mertensia paniculata (Ait) G. Don., Pyrola asarifolia Michx. and Rubus pubescens Raf.

Experimental Design and Treatments

The experiment was a split-plot design, with two replications (blocks), four residual canopy densities (two shelterwood seeding cuts - low and high residual densities, one uncut control and one conventional clearcut) in the main plots, and three site preparation treatments (blading, mixing and control) in the subplots. Plots for canopy treatment were 150 m x 150 m; the outer 25 m served as a buffer leaving a 1 ha area in the centre for sampling. Dominant and co-dominant leave trees, at the appropriate spacing, were marked prior to cutting. Harvesting was done by feller-buncher in the winter of 1993/1994. Trees were skidded to the landing and processed with a stroke-delimber. Residual basal area was 16.5 m^2/ha aspen and 3.6 m^2/ha white spruce in the high residual density treatment (HD), 8.7 m^2/ha aspen and 3.8 m^2/ha white spruce in the low residual density treatment (LD), and 18.0 m^2/ha aspen and 12.5 m^2/ha white spruce in the control (CT). In the early summer of 1994, each canopy treatment plot was subdivided into three 100 m long and 33 m wide subplots for mechanical site preparation. Subplots were either bladed, mixed or left untreated (control). Blading removed the organic layer (L, F and H horizons) and part of the upper mineral soil to a depth of 11 to 13 cm, exposing the eluviated Ae horizon, while in the mixing treatment, the organic layer and top A horizon were mixed to about 10 to 13 cm depth. Both blading and mixing were done by a Thomas 233 Skidsteer loader fitted with either a hydraulic angle tilt blade (160 cm wide) or a MJ Merri-Crusher mixing head (140 cm wide).

Measurements of Seedling Environments

Measurements of PPFD were made on cloudless days at 1.3 m above the ground between 10:00 and 14:00 solar time in late June 1994, at 15 locations in each site preparation subplot. At each location, 12 readings were taken in an area of about 7 m^2 and averaged. Light transmission through the canopy was calculated as a ratio between the average PPFD of each subplot and above canopy PPFD, which was recorded in open locations at the start and finish of light measurements for each subplot.

The Red:Far Red ratio (F:FR, 654-664/724-734 nm) was measured with a portable spectroradiometer (Li-Cor. 1800, Lincoln, NB) between 10:00 and 15:00 solar time on clear days in late June, 1994. Nine locations were sampled at 1.3 m height in each subplot.

Daily mean, maximum and minimum air temperatures at 0.50 m above the forest floor were measured in both replicate blocks of the clearcut (CC), HD and CT treatments, using type 101 thermistors (Campbell Scientific, Inc., Logan, UT). Relative humidity at 0.50 m height was measured with a type 201 RH thermistor probe (Campbell Scientific Inc., Logan, UT). Two temperature and one humidity measurement stations from each of the three canopy densities was maintained throughout the growing season of 1995. All temperature and humidity sensors were suspended in the centre of a horizontal white PVC pipe (5.0 cm diameter and 30 cm long for temperature sensors and 8.0 cm diameter and 50 cm long for RH sensors) to shield them from direct radiation. Small holes were drilled at the side and bottom of the pipes to prevent heat and water buildup. Sensors were connected to a datalogger (CR21, Campbell Scientific Inc., Logan, UT) and daily mean, maximum, and minimum temperatures and relative humidities were stored.

Five thermocouples (24-gauge copper/constantan) were installed at 0.10 m depth and three at 0.30 m depth near the centers of spots for planting seedlings in each site preparation subplot. At each installation, a block of soil was removed to the correct depth and thermocouples were horizontally inserted into the soil before replacing the soil. Instantaneous measurements of soil temperature were made within 2 hours of solar noon on May 5, 19, July 22, August 2, and Sept. 20, 1995 with a microprocessor thermometer (Model HH21, Omega Engineering Inc., Stamford, CT).

Performance of Planted Seedlings

White spruce seeds were collected about 60 km south of the sites and seedlings were grown at the British Columbia Ministry of Forests nursery in Ladner, BC. One year old seedlings raised in PSB 4-15 B containers (styroblocks of 4 cm diameter and 15 cm depth, Beaver Plastic Ltd., Edmonton, Alberta) as summer stock have finished height growth for the current growing season. They had set a bud and stems were hardened, and would not flush until the following spring after planting. These seedlings averaged 18.1 ± 0.5 cm (mean ± standard error) in height and 0.4 ± 0.1 cm in root collar diameter when planted on June 21-22, 1994. Ten planting positions were systematically selected in each site preparation subplot and five seedlings were planted at each position. In the blading treatment, seedlings were planted with the entire root plug in mineral soil, whereas in mixing and control site preparation treatments, about a third of the root plug was in mineral soil and the rest was in the mixed or lower organic (LFH) layer.

The following seedling performance variables were assessed: bud break of terminals and terminal bud mortality of live seedlings, gas exchange parameters, seedling mortality, gas exchange parameters (net photosynthesis and stomatal conductance), and height and diameter growth of seedlings which were free from damage on the current leader. Bud break of terminals was checked on May 18, May 25, and June 2, 1995 during the first bud break of seedlings after planting. Seedlings with slightly opened scales exposing green foliage were recorded as flushed. Surveys on seedling and terminal bud mortality in subplots were carried out three times, May 18/95, Sept. 25/96, and Sept. 5/97. Height increment was measured for healthy seedlings (no damaged terminal) after terminals were fully extended at the end of each growing season and seedling diameter was measured in the fall of 1997.

Due to time limitations, gas exchange parameters were followed on the seedlings from three residual densities, CT, HD and CC, and two site preparation treatments, control and blading only. Measurements were taken on May 22, August 18, and September 25, 1996, the second growing season after planting. The first (spring) measurement was on one-year-old foliage (1995 cohort) while the summer and fall measurements were on current foliage (1996 cohort). All sample shoots were taken from the upper lateral branches except for the first measurement in springtime when only terminals were available. At each sampling date, one of the five seedlings at each subplot was chosen for measurement. Measurements were made in the morning for block one and in the afternoon for block 2 to reduce the effects of variable environmental conditions.

Gas exchange parameters were measured using a portable gas analysis system equipped with a conifer cuvette (LCA-2/PLC-C, Analytical Development Corp., Hoddenson, England). Relative humidity of incoming air was adjusted by using silican gel desiccant so that the relative humidity in the cuvette during measurements was approximately equal to the relative humidity of ambient air. The light source was 12 V, 39 W from a quartz halogen lamp (HR16 SQFL, Philips, NY) positioned on the top of the cuvette to provide photosynthetically saturating light of ca. 1000 $\mu mol\ m^{-2} s^{-1}$. Following gas exchange measurements, the sampled shoots were picked and frozen for later leaf area determinations. Needles were removed form the stems and projected one-sided leaf area determined using SigmaScan Pro image analysis software (Jandel Scientific, San Rafael, CA) and a ScanJet 4c scanner (Hewlett Packard, Palo Alto, CA) with an image resolution of 3000 dots per inch.

Data Analysis

Net photosynthesis at saturating light ($\mu mol\ m^{-2}\ s^{-1}$) and stomatal conductance to H_2O ($mmol\ m^{-2}\ s^{-1}$) were calculated as described by Caemmerer and Farquhar (1981).

Analyses of variance were performed on photosynthesis and soil temperature, and on accumulated height increment (total height increment in three years) and seedling diameter averaged for each planting position, using the general linear models procedure (PROC GLM) available in SAS Release 6.11 (SAS Institute Inc., 1995). Repeated measurements of photosynthesis and soil temperature over time were treated as a split-split factor as described by Little and Hills (1978). Accumulated height increment and diameter data were excluded in the case that all five seedlings of a planting position were damaged or died. These affects were detected by the analysis of seedling mortality.

Frequency data of bud break, mean terminal bud mortality, and accumulated seedling mortality of each subplot over the three years were analyzed with the categorical data modeling procedure (PROC CATMOD) in SAS. Data were combined across seedlings within the subplot to produce an adequate sample size. As bud break was just starting on May 18 and was almost completed on June 2, data on May 25 reflected the biggest difference among the treatments and were used for analysis.

Results

Microclimate

Reduction of canopy density increased light transmission and the R:FR ratio (Table. 1). The relationship between the light transmission and residual basal area was nearly linear ranging from 20% in the uncut stands to 100% in the clearcut. For the light quality, there was little difference in R:RF ratio between the two shelterwood canopies, LD and HD, but a large difference between the uncut control, the shelterwoods, and the clearcut.

Maximum air temperature and frequency of frost increased and minimum temperature decreased with the reduction of residual density (Table 1). On average, maximum temperature was about 2.2 °C warmer in the HD and 2.7 °C warmer in the CC compared to that in the CT. Minimum temperature averaged over the entire growing season was 0.4 °C lower in the HD and 2.2 °C lower in the CC than that in the CT. Of the 167 days of observations in 1995, 27 night frosts (minimum temperature below 0 °C) were recorded in the CT, 28 in the HD, and 49 in the CC. Total number of frosts below -2 °C was 11 in the CT, 15 in the HD, and 23 in the CC. The frost-free period included all of June, July and August, except in the clearcuts where 8 light frosts (minimum temperature between 0 and -2 °C) were recorded during this period.

Relative humidity decreased as residual density decreased (Table 1). Mean and minimum RH averaged over the whole sampling period was 2.9% and 3.5 % lower in the HD and 8.1% and 7.3% lower in the CC than those in the CT.

The overall treatment effect on soil temperature was statistically significant only by site preparation treatment (P=0.0026 for 0.10 m depth and 0.0011 for 0.30 m) despite the fact that there was a trend for increased temperature with the reduction of residual density in the canopy (Fig.1). Mean soil temperature at 0.10 m depth was 1.5 to 3 °C higher in bladed and mixed site conditions than that in the unscarified treatments in the three measurements in spring and early summer (Fig.1). The difference greatly decreased in August and appeared to be reversed in September, with temperature highest in the control site. Similar treatment effects and seasonal patterns existed at deeper soil (0.30 m) but there were smaller differences among treatments. There was no interaction of residual density by site preparation treatment at either 0.10 or 0.30 m depth.

Seedling Performance

Bud break, mean terminal bud mortality, and accumulated seedling mortality after three years were strongly associated with residual density (P<0.0001 for bud break and mean terminal bud mortality and P=0.0038 for accumulated seedling mortality). On May 25 of 1995 for example, 51.5% seedlings had flushed under the HD canopy, 45.8% under the LD canopy, 22.0% under the CT canopy, and 22.8% under CC canopies. Mean terminal bud mortality and accumulated seedling mortality showed a similar pattern over the overstory treatments (from CT, HD, LD to CC): 33.0%, 7.9%, 13.5%, and 17.0% for terminal mortality and 22.3%, 8.3%, 9.0%, and 13.3% for seedling mortality. Most seedling mortality in the clearcut (7.3%) occurred before the first growing season (between June 21-22/94 and May 18/95), apparently from water stress while most seedling mortality under the canopy (11.7% in the CT, 3.6% in the HD, and 7.3% in the LD) occurred in the first growing season after planting from a fungal agent (likely one of the storage molds of conifer seedlings) (Hiratsuka 1987).

Site preparation treatment had a significant effect only on the accumulated seedling mortality (P<0.0001). Mean seedling mortality was 7.3% and 9.0% for bladed and mixed sites but as high as 23.5% for the control. None of the interactive effects of residual density and site preparation was significant except on seedling mortality (P=0.0446) where scarified sites under partial canopies of shelterwoods had substantially lower mortality than other treatment combinations.

There was a trend for higher net photosynthesis for seedlings growing under a canopy (P=0.0358) and seedlings on treated (bladed) site conditions (P=0.0983), while stomatal conductance was not significantly affected by either residual density or site preparation despite oapparently higher rates for seedlings in the LD and the CC compared to the CT (Fig.2). No interactions were significant for either net photosynthesis or stomatal conductance.

At the end of the three years, the total height increment appeared to be weakly affected by residual density (P=0.0574) and site preparation (P=0.0984). Similarly, effects on seedling diameter were nearly significant for residual density (P=0.0511) and site preparation (P=0.0333). Interactions were not significant. For height growth, treatments were ranked (highest to lowest) LD, HD, CC, and CT. For seedling diameter the rank was LD, CC, HD, and CT (Table 2). Among the three site preparation treatments, both height increment and seedling diameter were highest in the mixing and lowest in the control treatment.

Discussion

Results from this study suggest that shelterwoods can provide a good compromise in the regeneration environment between the extremes of a clearcut and an intact boreal mixedwood forest. Relative to the intact canopy, the shelterwood increased light transmission from 20% in the CT to 46% in the HD and 73% in the LD, a level that has been shown to produce maximum height growth of young white spruce (Logan 1969; Stiell 1976; Lieffers and Stadt 1994). Diameter growth appeared to benefit from the higher light level in the LD treatment, which is consistent with earlier observations (Eis 1967; Logan 1969; Lieffers and Stadt 1994).

Relative to the clearcut, the shelterwoods had higher humidity, cooler maximum and warmer minimum temperatures, and reduced occurrence and severity of night frost; these are all beneficial to establishing white spruce (Grossnickle and Blake 1986, 1987; Colombo and Teng 1992; Marsden et al., 1996; Groot and Carlson 1996). Decreased light transmission and R:FR ratio under partial canopy could reduce photoinhibition (Lundmark and Hällgren 1987; Dang et al. 1992) and increase the resource partitioning to aboveground growth (Riotchie 1997). Man and Lieffers (1997) observed a significant decrease of net photosynthesis in white spruce seedlings planted on open sites compared to seedlings under forest canopy during frost periods in spring and fall. Seedlings under shelterwood canopies showed earlier budbreak, reduced terminal bud and seedling mortality, increased capacity for photosynthesis, and improved growth. All of these suggest that shelterwood system can be used as an alternative to improve the extreme conditions created by clearcutting and promote white spruce regeneration. Between the site preparation methods used, soil mixing produced better height and diameter growth than blading treatment, probably due to higher water holding capacity and nutrient availability in mixed sites.

The fungal attack on seedlings planted beneath an canopy was likely derived from nursery-borne fungi. We hypothesize that these fungi were killed in clearcut conditions but the high humidity conditions under the denser canopies, especially the uncut control, allowed them to survive. This suggests that extra care is needed to ensure that these fungi are not present on seedlings that are to be underplanted.

Site preparation affected photosynthesis, seedling mortality, and seedling growth likely due to the improved soil conditions. Besides the increased soil temperatures observed in this study, site preparation can also positively influence bulk density, soil moisture, gas exchange in the soil, nutrient availability, and relative humidity and air temperature near the ground surface (Stathers 1989; Örlander et al. 1990; Spittlehouse and Childs 1992; Munson et al. 1993), especially immediately following treatment. For the newly planted seedlings, however, improvement in soil moisture conditions is probably most critical (Rietveld, 1989). Site preparation, especially mixing treatment, can not only improve water holding capacity of the soil, but also reduce water consumption by vegetative plants.

Average soil temperatures at both 0.10 and 0.30 m depths observed in this study were generally lower than the optimum soil temperature for white spruce seedlings (about 15 to 25 °C) (Brix 1972; Grossnickle and Blake 1985). Shelterwood treatment reduces overstory density and site preparation reduces the vegetation cover on forest floor, both of which can result in an increase of light received on the ground surface and raise soil temperature. Increased soil temperature has been shown to positively influence water uptake (Teskey et al. 1984), and root growth and photosynthesis of white spruce seedlings (Grossnickle and Blake 1985). As white spruce roots are distributed mostly in upper organic layers of the soil (Strong and La Roi 1983), the increased soil temperature is probably more important to boreal forest species with deeper root systems, such as aspen (Strong and La Roi 1983).

In conclusion, shelterwood and site preparation treatments improved environmental conditions and seedling performance of white spruce in the first three years after planting. Under the shelterwood canopy, a residual basal area of 12.5 to 20.1 m^3/ha appeared to provide adequate protection against environmental extremes according to our direct measurements and seedling response. This is in agreement with the suggestions by Waldron (1966) and Waldron and Kolabinski (1994) for boreal mixedwood stands. LD treatment had better seedling growth while HD treatment resulted in lower seedling mortality and terminal bud mortality. The determination of optimum residual density of shelterwoods is therefore a balance between seedling growth and control of environmental extremes, depending on stand and site conditions.

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List of Figures

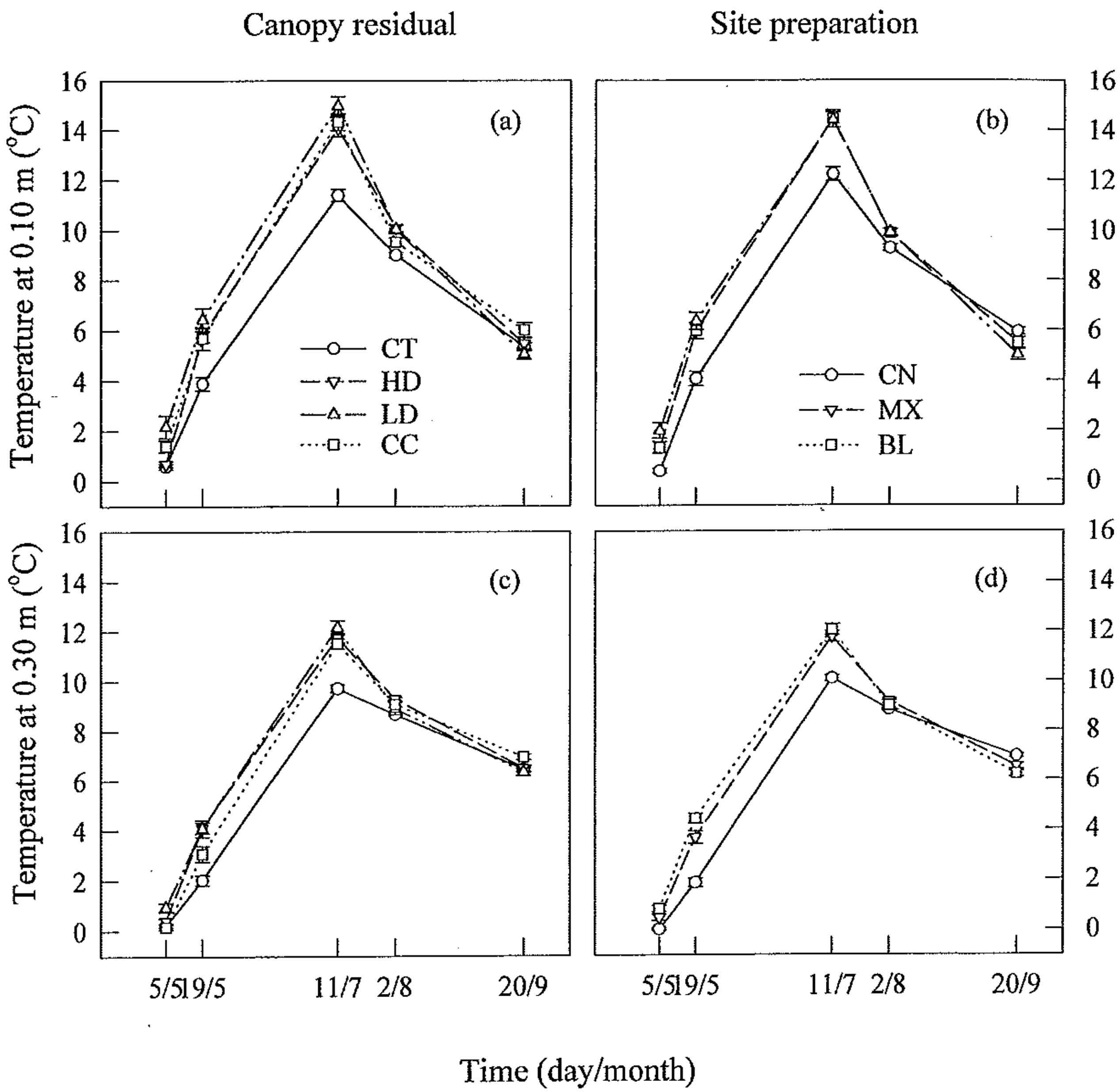

Figure 1
Man and Lieffers

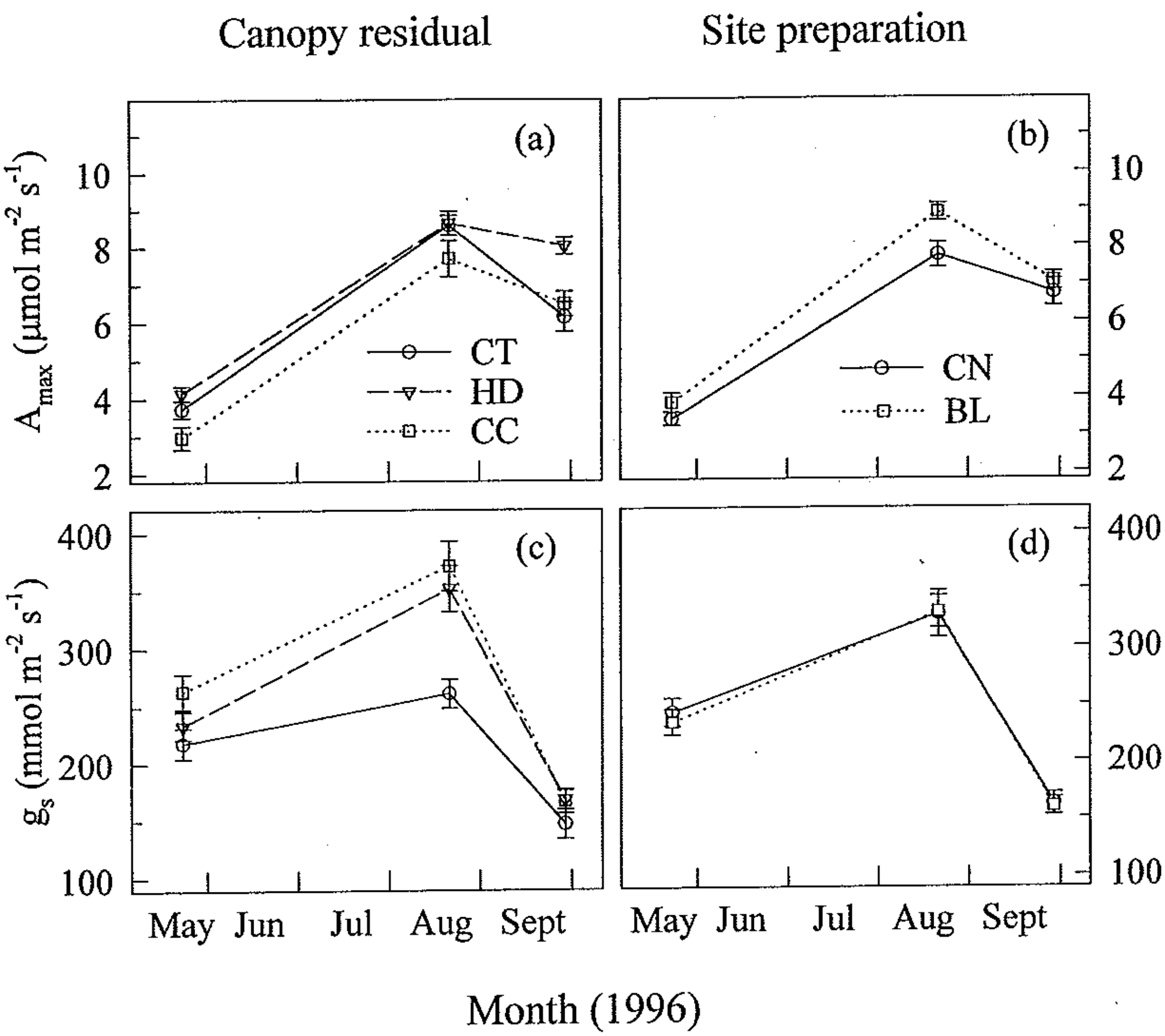

Figure 2
Man and Lieffers

Table 1. Microclimates under canopy treatments. Temperature and humidity expressed as the differences between control and treated canopies are averaged from early May to mid-October, 1995, the second growing season after treatment. Relative light transmission was measured in late June, 1994.

Residual density	Control	High residual density	Low residual density	Clearcut
Relative temperature (0.50 m)				
Maximum	0.0	+2.2	---	+2.7
Minimum	0.0	-0.4	---	-2.2
Frost occurrence (0.50 m)				
< 0 °C	27	28	---	49
< -2 °C	11	15	---	23
Relative RH (0.50 m)				
Minimum	0.0	-3.5	---	-7.3
Mean	0.0	-2.9	---	-8.1
Light (1.30 m)				
% transmission	20	46	73	100
R:FR ratio	0.51	0.91	0.92	1.09

Table 2. Seedling growth (mean±SE)

Canopy treatment	Control	High residual density	Low residual density	Clearcut
Height increment	13.91±0.97	29.00±0.86	30.77±0.77	24.40±1.00
Total diameter	4.99±0.12	7.46±0.15	8.07±0.18	7.60±0.20

Site preparation	Control	Blading	Mixing
Height increment	22.51±1.00	24.43±0.99	26.70±1.16
Total diameter	6.45±0.17	7.23±0.18	7.44±0.22