AN ABSTRACT OF THE THESIS OF

Anne M. Macadam for the degree of Master of Science in Soil Science presented on April 3, 1991.

Title: Effects of Microsite Alteration on Soil Climate, Nitrogen Mineralization, and Establishment of *Picea Glauca x Engelmannii* Seedlings in the Sub-boreal Spruce Zone of West-central British Columbia

Abstract approved: Redacted for Privacy
David D. Myrold

Site preparation treatments are often used prior to the planting of clearcut forest lands to improve planter access and to increase the number and quality of planting spots. Most mechanical site preparation treatments alter the configuration and material composition of surface soil materials, and can have marked effects on soil properties important to seedling survival and growth. Effects of some of these treatments on soil moisture, soil temperature, rates of nitrogen mineralization, and the establishment of *Picea glauca x engelmannii* seedlings were examined on fresh, moist, and wet sites in the moist cold subzone of the Sub-boreal Spruce Zone in west-central British Columbia. Four types of microsite alteration were investigated: forest floor removal (spot scalping), soil mounds over inverted sections of forest floor (inverted mounds), mineral soil mounds over a mineral soil surface, and inversion of the forest floor and mineral soil in place.

Soil temperature was monitored continuously and soil moisture weekly at the 10-cm depth in 16 combinations of site and microsite treatment during two growing seasons. The response of seedling height and diameter growth was monitored for three growing seasons. Effects of altering soil temperatures through mechanical treatments on rates of nitrogen mineralization were examined by incubating a standard soil material in a range of microsites created by six combinations of site and mechanical treatment. Effects of substrate quality and soil temperature on rates of nitrogen mineralization were examined in paired mounded and untreated spots in fresh, moist, and wet sites.

In all sites, early growing season soil temperatures in the seedling rooting zone were substantially warmer in inverted mounds than in other treatments. Spot scalping increased temperatures slightly relative to controls in the fresh site, but had little or no warming effect on moist and wet sites. Inverted mounds became substantially drier than other treatments during periods of low rainfall, particularly in the fresh site. After three growing seasons, seedling height growth was greatest in inverted mounds, irrespective of site. Amounts of nitrogen mineralized in a standard soil material during incubation for 77 days in the field were significantly greater for samples placed in inverted mounds than for those placed in other microsite treatments. There was a significant positive correlation between amounts of nitrogen mineralized during field incubations and degree hour sums calculated for associated microsite treatments and sites. Both substrate quality and soil thermal regime affected rates of N mineralization in samples from paired mounded and untreated spots, and an interaction was observed between the two factors.

Effects of Microsite Alteration on Soil Climate, Nitrogen Mineralization, and Establishment of *Picea Glauca x Engelmannii* Seedlings in the Sub-boreal Spruce Zone of West-central British Columbia

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EFFECTS OF MICROSITE ALTERATION ON SOIL CLIMATE, NITROGEN MINERALIZATION, AND ESTABLISHMENT OF *PICEA GLAUCA X ENGELMANNII* SEEDLINGS IN THE SUB-BOREAL SPRUCE ZONE OF WEST-CENTRAL BRITISH COLUMBIA

1 INTRODUCTION

This study took place in the moist cold subzone of the Sub-boreal Spruce Zone[1] (SBSmc) of west-central British Columbia. It is an area dominated by upland forests of white spruce (*Picea glauca* (Moench) Voss) and its naturally occurring hybrid *Picea glauca x engelmannii* (interior spruce), *Abies lasiocarpa* (subalpine fir), and *Pinus contorta* (lodgepole pine) (Pojar *et al.* 1984). It has a cold sub-boreal continental humid climate: winters tend to be snowy and severe, and summers relatively warm, moist, and short.

Several thousand hectares of clearcut forest lands are planted to interior spruce and lodgepole pine seedlings in the SBSmc annually. Unfortunately, as in many parts of British Columbia, conditions following clearcut logging in the SBSmc are seldom optimal for the establishment and growth of planted conifer seedlings (McMinn and Hedin 1990). Logging slash often presents a barrier to planting, and particularly in wet ecosystems, low soil temperatures and flooding are common problems.

Whereas broadcast burning has historically been the main form of site preparation in the area and has been used successfully on well- to imperfectly-drained sites, seedling survival and growth on poorly drained sites is often unsatisfactory. In addition, there is a growing resistance among the public to the use of prescribed fire. Consequently, forest managers are actively seeking mechanical alternatives to burning, to improve rates of survival and growth on wet sites, and to improve plantability on sites that have historically been successfully treated using prescribed fire.

A wide range of mechanical treatments are possible. The forest floor may be scalped, mixed, or inverted, resulting in planting spots which may be raised, depressed, or level relative to the undisturbed soil surface (McMinn and Hedin 1990). By altering the configuration of mineral soil and forest floor materials, soil moisture, temperature, and nutrient regimes may be subtly or dramatically

[1]Within the ecological classification system used by the B.C. Ministry of Forests, the biogeoclimatic subzone consists of unique sequences of geographically related ecosystems influenced by one type of regional climate. The biogeoclimatic zone is a large geographic area with a broadly homogeneous mesoclimate.

affected at the microsite level. Used judiciously, mechanical treatments can alleviate adverse environmental conditions such as flooding and low soil temperatures. But different sites may respond very differently to the same treatment. Local climatic conditions, and site and soil factors such as topography, microtopography, drainage, soil texture and coarse fragment content, forest floor depth, and soil depth over bedrock or impermeable layers combine to determine the nature and severity of growth-limiting factors on each site, and the way in which these factors will respond to treatments.

Operational experience with mechanical site preparation in the SBSmc has primarily been with patch scarification and disk trenching, while mounding has only begun to be used in the area within the past two years. The response of seedlings has been varied, and not been well-documented. Although research trials have examined effects of mechanical treatments on soil climate and interior spruce establishment in more interior subzones of the SBS (Draper *et al.* 1985; Bedford 1986) and the higher elevation Engelmann Spruce - Subalpine Fir Zone (ESSF) (Bassman 1989), no similar work had been undertaken in the SBSmc subzone.

The purpose of this study was to provide information about the way that soil climate, rates of nitrogen mineralization, and seedling growth can be expected to respond to various types of mechanical treatment within the climatic context of the SBSmc subzone. Specific objectives were:

1. to measure and compare the effects of four types of microsite alteration on soil temperature and moisture on fresh, moist, and wet sites;
2. to measure the response of interior spruce seedlings to these combinations of treatment and site; and
3. to investigate the effects of altered soil temperature regimes on rates of nitrogen mineralization.

1.1 Study Area

The study area is located approximately 80 km north-east of Smithers in west-central British Columbia (54°44'N, 126°25'W) (Fig. 1). Annual precipitation in the area averages 513 mm, approximately half of which falls as snow and the remainder as rain, which tends to be fairly evenly distributed during May to October. Air temperatures average 14°C in July and -12°C in January (Atmospheric Environment Services 1982). The elevation of the study area is 1050 m, and the terrain is flat to gently sloping, with a north aspect.

Study plots were established within an 80-ha cutblock which was logged in winter 1982-83, broadcast burned in September 1983, and operationally planted with interior spruce seedlings in spring of 1984. Seedling survival following this initial planting was poor in wetter portions of the block, and these were replanted in 1987.

Three distinct ecosystems were identified within the block, associated primarily with variations in soil drainage: mesic bunchberry-moss, oakfern, and horsetail flat site series of the SBSmc subzone (Pojar *et al.* 1984). These will be referred to as fresh, moist, and wet sites respectively.

Modal soil pits were described adjacent to one plot per site. Soil characteristics associated with each are depicted in Figure 2 and summarized in Table 1.

1.2 Experimental Treatments

Four types of microsite alteration were examined: spot scalping, soil inversion, inverted mounding, and mineral-on-mineral mounding, in addition to an untreated control (Fig. 3). Hand tools were used to carry out treatments in October, 1986.

Scalped spots were 60 x 80 cm in area. In fresh site plots, the forest floor and underlying mineral soil were removed to a total depth of 10 cm relative to the undisturbed forest floor surface. In moist and wet site plots, the forest floor and mineral soil (if present) were removed to a total depth of 15 cm.

Inverted spots were formed by excavating a block of soil (top surface dimensions 60 x 60 cm) to a depth of 20 cm and inverting it in place.

For inverted mounds, a 40 x 40-cm section of moderately decomposed forest

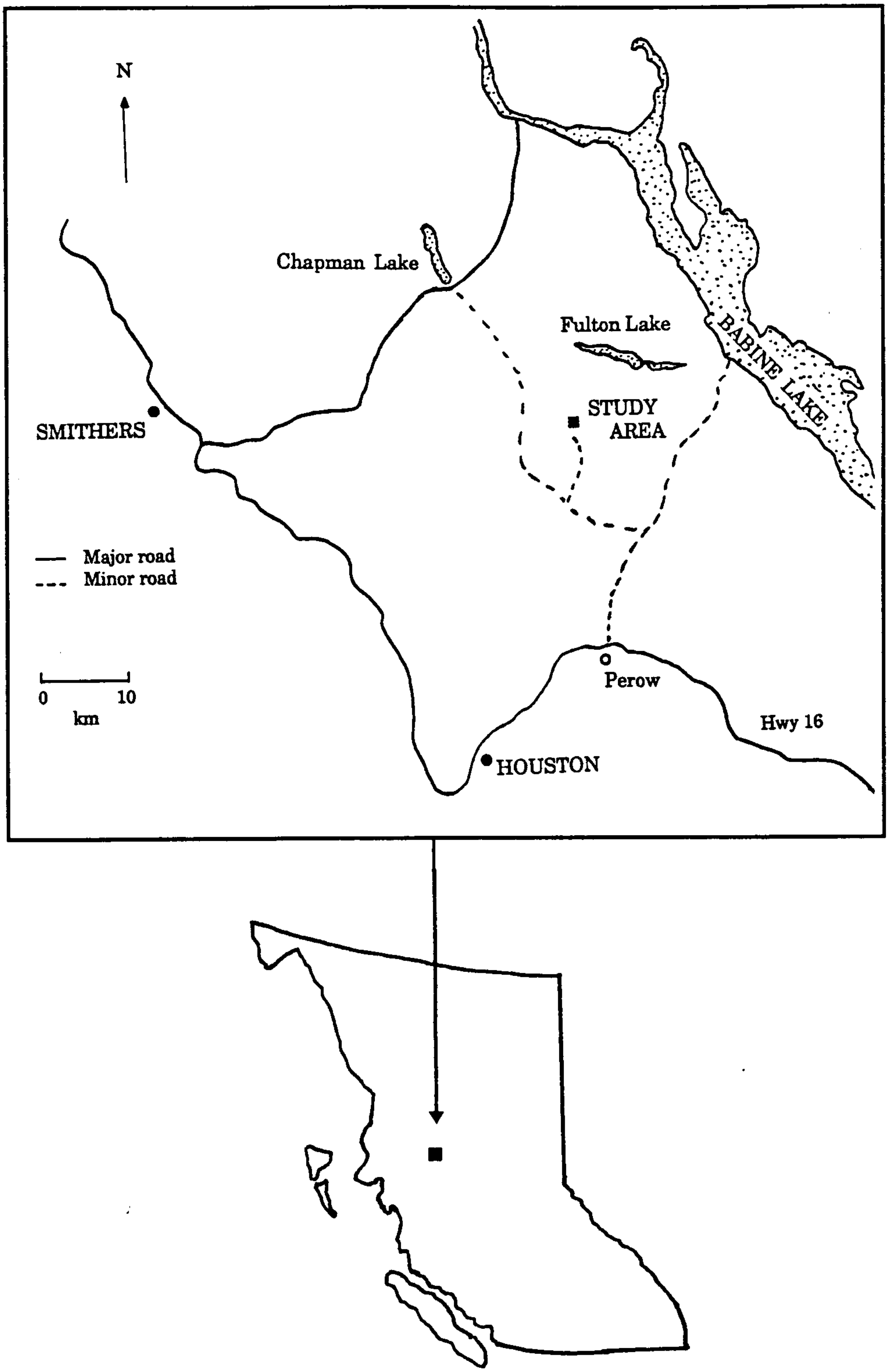


FIGURE 1. Location of the study area in west-central British Columbia.

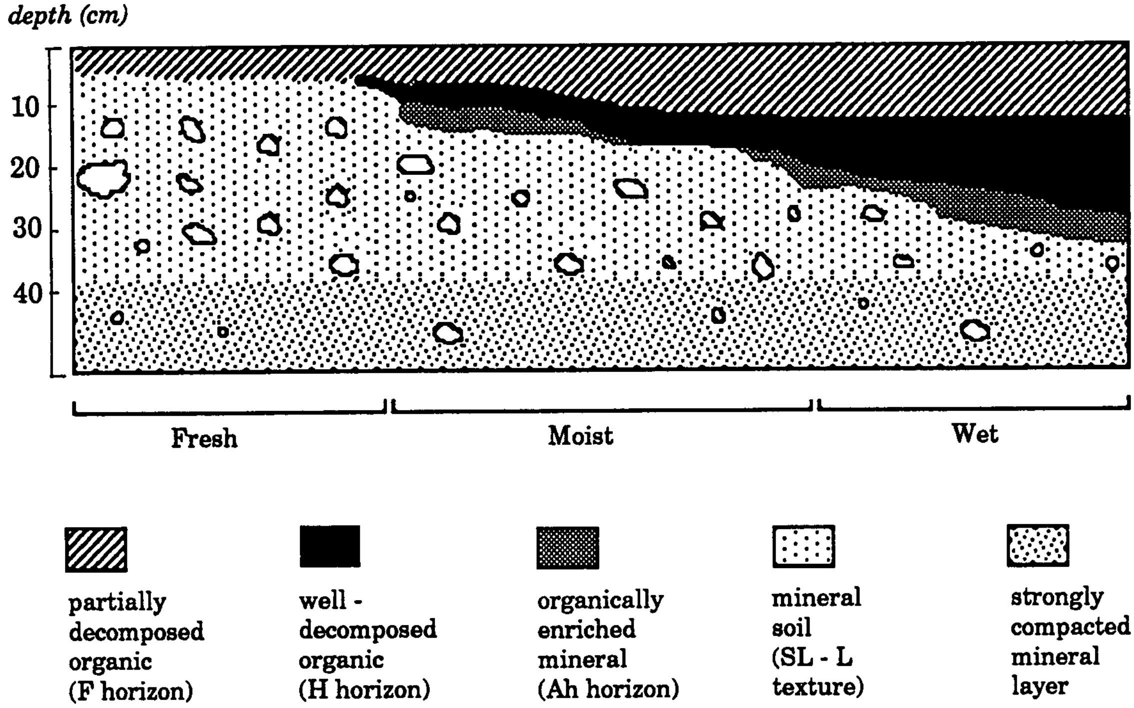


FIGURE 2. Diagram of soil profiles in fresh, moist, and wet sites.

TABLE 1. Summary of site and soil characteristics associated with fresh, moist, and wet sites.

Site	Surficial materials	Soil classif.[1]	Particle size class	Humus form classif.[2]	Forest floor depth (cm)	Drainage class	Rooting depth (cm)
fresh	morainal blanket ≈ 35 cm ablation/ compact basal till	Brunisolic Gray Luvisol	coarse loamy/ fine loamy	Orthi-hemimor	4-6	well drained	25-30
moist	morainal blanket, ≈ 35 cm ablation/ compact basal till	Gleyed Gray Gray Luvisol	coarse loamy/ fine loamy	Orthi-hemimor	12-15	imperfectly drained	20-25
wet	organic veneer/ compact basal till	Gleyed Dark Gray Luvisol	fine loamy	Hemi-hydromor	25-30	poorly drained	15-20

[1]Agriculture Canada Expert Committee on Soil Survey 1987

[2]Klinka *et al.* 1981

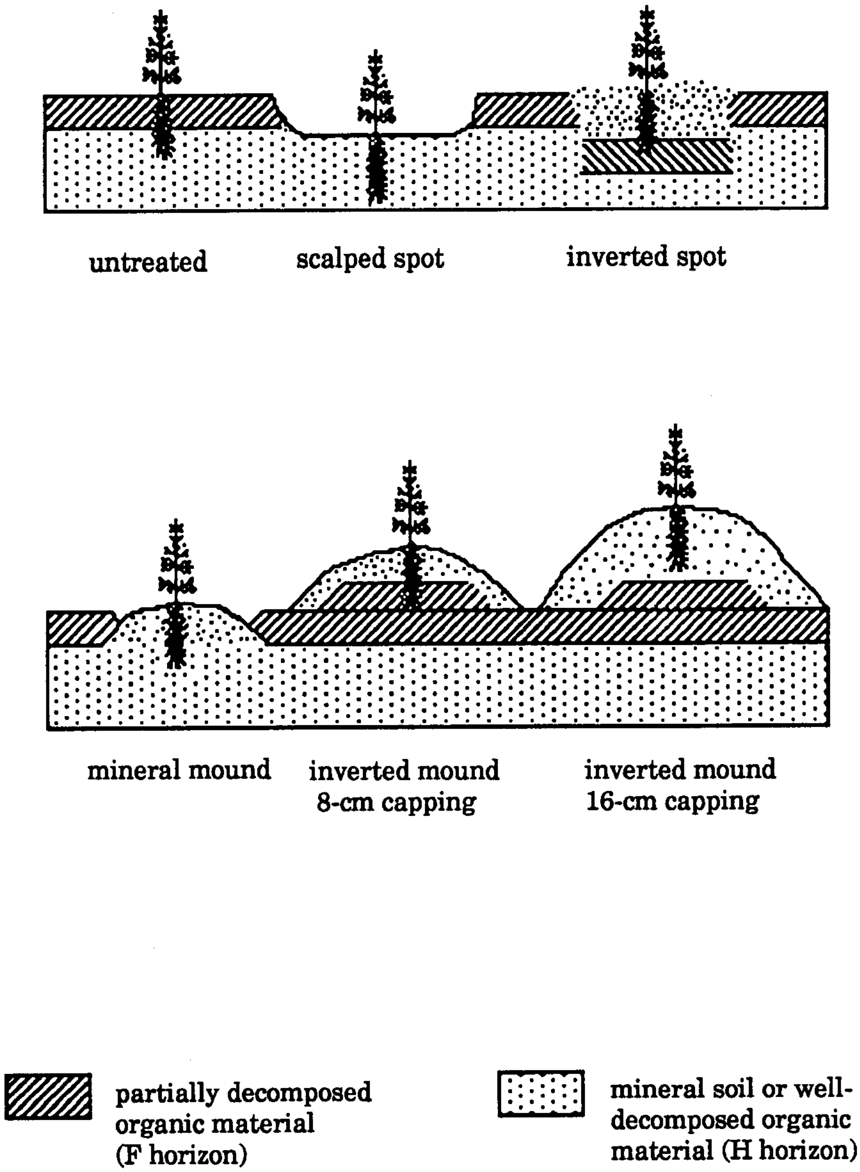


FIGURE 3. Diagram of experimental treatments.

floor materials (F horizon) was excavated, inverted, and placed on undisturbed forest floor adjacent to the excavation. The underlying well-decomposed organic materials (H horizon) and/or mineral soil materials were then deposited on the overturned mat to a depth of 8 or 16 cm, measured from the top of the upturned F horizon. Inverted mounds with 8-cm capping depths were included in the fresh site, while mounds with both 8 and 16-cm of capping were included in wet and moist sites. Finished dimensions of mounds were approximately 60 x 60 cm including shoulders.

Mineral-on-mineral soil mounds were constructed by removing the forest floor from a 40 x 40 cm area, and then placing a 10-cm layer of mineral soil over this surface. Since the depth of the forest floor exceeded 25 cm on the wet site, this treatment was only included in fresh and moist sites.

1.3 Experimental Layout, Design, and Analysis

The experimental factors examined in soil climate and seedling response components of the study are shown in Figure 4. Note that the lists of treatments are slightly different for each site.

Study plots were situated such that soil drainage, the depth of the forest floor, and the texture and organic matter content of mineral soils were as uniform as possible within plots. Five plots were established per site. Dimensions of plots on fresh and wet sites were 25 x 25 m to accommodate five replications of five treatments, including controls. Dimensions of plots on the moist site were 25 x 30 m to accommodate five replications of six treatments. Within each plot, each treatment was randomly assigned to five planting spots, spaced at 2-m intervals.

Experimental design varies among the components of the study and will be described separately in chapters on soil climate, nitrogen mineralization, and seedling response. Analysis of variance procedures were based on those described by Petersen (1985). All statistical analyses were carried out using the SAS statistical software package (SAS Institute 1988).

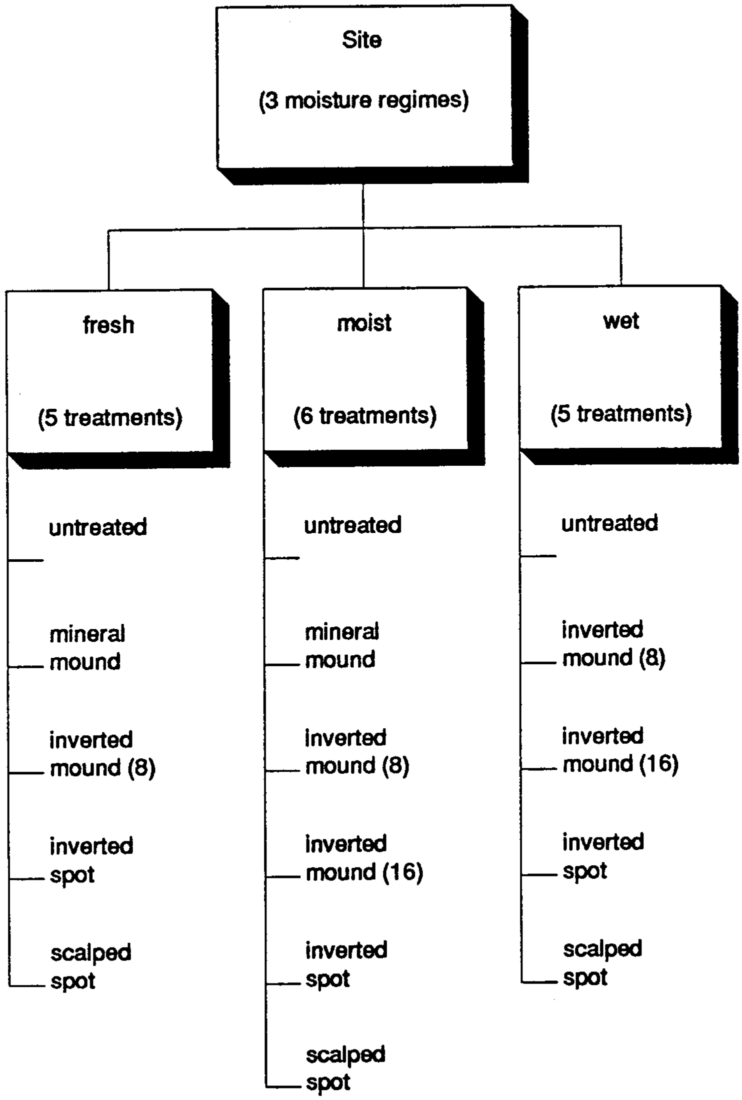


FIGURE 4. Experimental factors examined in soil climate and seedling response components of the study.

2 EFFECTS OF MICROSITE ALTERATION ON SOIL CLIMATE

2.1 Introduction

Soil climate can have a major impact on the establishment and growth of newly planted seedlings. Root growth and water uptake are strongly affected by soil temperature (Grossnickle and Blake 1985; Lopushinsky 1986), and insufficient or excessive soil moisture can cause seedling mortality and reduced rates of growth (Levan and Riha 1986; Örlander 1986; Grossnickle 1987).

In the SBSmc subzone of central B.C., soil moisture deficits generally occur only in very rapidly drained soils and during particularly dry years. Low soil temperatures and flooding are common problems however, particularly early in the growing season in moist and wet ecosystems (McMinn 1982). The selection of relatively warm, well-drained microsites for planting spots in these ecosystems can be crucial to seedling survival. Where there are an insufficient number of favorable microsites for planting following logging, mechanical treatments may be prescribed with the aim of creating microsites with improved growing season soil temperatures and aeration. A primary objective of this study was to assess the effectiveness of various types of mechanical treatment with respect to their influence on soil climate.

2.2 Methods

2.2.1 Air temperature and precipitation

Air temperature and precipitation were monitored to establish a macroclimatic record for experimental data and to observe the frequency of frost during the growing season. Air temperatures were recorded by dataloggers continuously at 20 cm and 1 m above the ground surface in three sample plots from May to October, 1987 and 1988. Precipitation was measured weekly from May to October, 1987 and 1988 using two standard rain gauges.

2.2.2 Soil temperature

Sensors were placed 10 cm below the soil surface in each combination of site and treatment (see Figs. 2, 3, and 4). The 10-cm depth was chosen to reflect conditions within the seedling rooting zone during the first two growing seasons after planting. Hourly average temperatures were recorded continuously by dataloggers from May to October, 1987 and 1988. Replication of temperature measurements was limited by the number of available datalogger channels to three per treatment in fresh and moist plots and one per treatment in the wet plot.

2.2.2.1 Soil temperature phases

It became apparent upon examining the data that the relationships among sites and treatments changed during the course of the growing season. For the purposes of analysis therefore, the growing season was divided into phases based on daily average soil temperatures at the 10-cm depth in untreated controls. Criteria for phases were drawn from the results of studies of white and Engelmann spruce seedling physiology, in particular the following two observations:

1. threshold soil temperatures for key physiological functions, including photosynthesis and water uptake appear to be between 7 and 9°C (Kaufmann 1975; Delucia 1986).

2. root and shoot growth increase with soil temperatures up to approximately 20°C (Chalupa and Fraser 1968; Heninger and White 1974; Dobbs and McMinn 1977), with substantial increases between 10 and 15°C (Dobbs and McMinn 1977).

Based on these observations, and on an examination of the 1987 data, the following five phases were identified:

1. spring: daily average soil temperature at 10-cm depth consistently below 8°C
2. early: daily average of 8 - 10°C
3. warm: daily average consistently above 10°C
4. cool: daily average occasionally below 10°C
5. late: daily average consistently below 10°C

Spring and late phases began and ended, respectively, with the commencement of monitoring on May 21 and termination of monitoring on October 1. The remaining dates were determined based on daily average temperatures at the 10-cm depth in untreated spots, averaged across all three sites.

2.2.2.2 Statistical analysis

Equipment failures occurred periodically during both 1987 and 1988, and observations of soil temperature in the wet site were not replicated. Consequently, statistical analyses were based on representative 5-day periods within each phase during the 1987 growing season for which there is a complete set of data for all treatments in moist and/or fresh sites.

The following parameters were calculated:

- average, maximum, and minimum temperatures
- sum of degree hours above 10°C (5 - day total)
- average hours per day above 8°C

The data were sufficiently complete to permit the statistical analysis of differences among treatments during all five phases for the fresh site, however only warm, cool, and late phase data could be analyzed in the case of the moist site. A two-way analysis of variance (ANOVA) was used to assess differences between moist and fresh sites during the latter three phases in 1987 (Table 2).

TABLE 2. ANOVA for effects of site and treatment on soil temperature.

Source	Df
Treatment	4
Site	1
Site * Treatment	4
Error	20
Total	29

For fresh and moist sites individually, analyses included one-way ANOVA's, contrasts, and Tukey's Studentized Range (HSD) tests for each phase in 1987 for which there was a complete set of data (Table 3).

2.2.3 Soil moisture

Gypsum resistance blocks, approximately 2 cm in diameter, were placed such that the top of each block was at a depth of 10 cm from the soil surface in seven randomly chosen spots per combination of site and treatment. Readings were

TABLE 3. ANOVA's and contrasts for effects of treatments on soil temperature (moist and fresh sites).

Source of variation	Moist Df	Fresh Df
Treatments	5	4
Error	12	10
Total	17	14
Contrasts		
inverted mounds vs. other treatments	1	1
untreated vs. all treatments	1	1
untreated vs. scalped spots	1	1
mineral mound vs. inverted mound	1	1
8 vs. 16-cm inverted mounds	1	-

taken manually at weekly intervals from early June to mid-September of 1987 and 1988. Resistance meter readings were converted to estimates of soil water potential based on a calibration curve derived from the pressure plate analysis of a sample of the moisture blocks.

Statistical analyses were based on the number of observations of soil water potential at greater than -0.05 (moist), less than -0.2 (slightly dry), and less than -0.3 MPa (moderately dry) out of 16 weekly sampling dates from early June to mid-September 1987 and 1988. The -0.2 MPa level was chosen for the purposes of data analysis based on the observation of Lopushinsky and Klock (1974) of declining transpiration rates in Engelmann spruce and other conifers below that level. Soil water potentials less than -0.3 MPa was chosen as the third parameter because soils in moist and wet sites seldom fell below that level, but were visibly drier at that level than at -0.2 MPa.

A three-way ANOVA (Table 4) was used to assess the effect of site, year, and the four treatments common to all three sites (untreated, scalped and inverted spots, and inverted mound (8)) on the number of observations of soil water potential at greater than -0.05, -0.20, and -0.30 MPa. Two-way ANOVA's were used to reassess year and treatment effects within each site individually, in order to examine the complete set of treatments (Table 5). Year and treatment interactions were found to be significant for the fresh site, so a one-way ANOVA was done to examine relationships among treatments and years (Table 6). Contrasts and Tukey's Studentized Range (HSD) test ($p < 0.05$) were used to assess differences among treatments.

TABLE 4. ANOVA for effects of year, site and treatment on soil moisture.

Source	Df
Site	2
Year	1
Treatment	3
Site * Year	2
Site * Treatment	6
Treatment * Year	3
Site * Year * Treatment	6
Error	144
Total	167

TABLE 5. ANOVA for effects of year and treatment on soil moisture, by site.

Source	Fresh Df	Moist Df	Wet Df
Year	1	1	1
Treatment	4	5	4
Year * Treatment	4	5	4
Error	60	72	60
Total	69	83	69
Contrasts			
inverted mounds vs. other treatments	1	1	1
untreated vs. all treatments	1	1	1
untreated vs. scalped spots	1	1	1
mineral mound vs. inverted mound	1	1	-
8 vs. 16-cm inverted mounds	-	1	1

TABLE 6. ANOVA for effects of treatments on soil moisture in the fresh site during both years.

Source	Df	
Treatment	9	(5 treatments x 2 years)
Error	60	
Total	69	

2.3 Results

2.3.1 Air temperature and precipitation

Cumulative degree days and air temperatures for May to October, 1987 and 1988 are shown in Figures 5 and 6, and cumulative and weekly rainfall are shown in Figure 7. Air temperatures were higher in general from mid-May to mid-August in 1987 relative to 1988, and 1987 was a considerably drier year than 1988, particularly from May to early July.

During both years, daily maximum air temperatures measured 20 cm above the forest floor surface were warmer than those measured at 1 m by 2 - 3°C on average, whereas daily minima were consistently lower, by 1.5°C on average (Fig. 8). Temperatures below freezing occurred during July and August twice as frequently at 20 cm (seedling height) than at the 1-m height. Frost damage to seedlings was observed in several plots during both years.

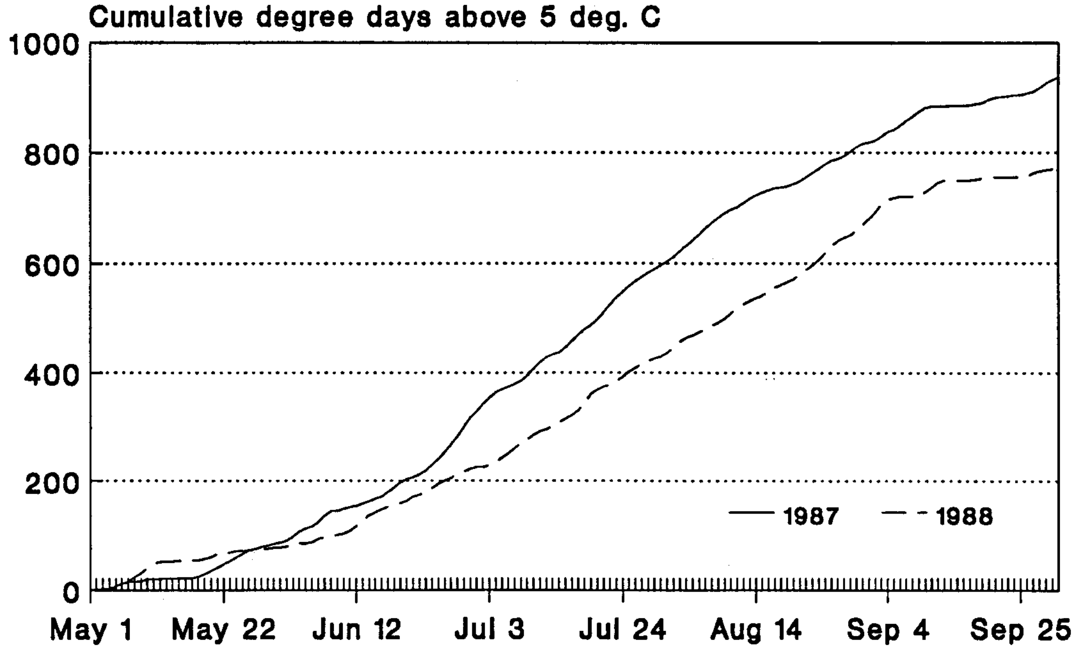
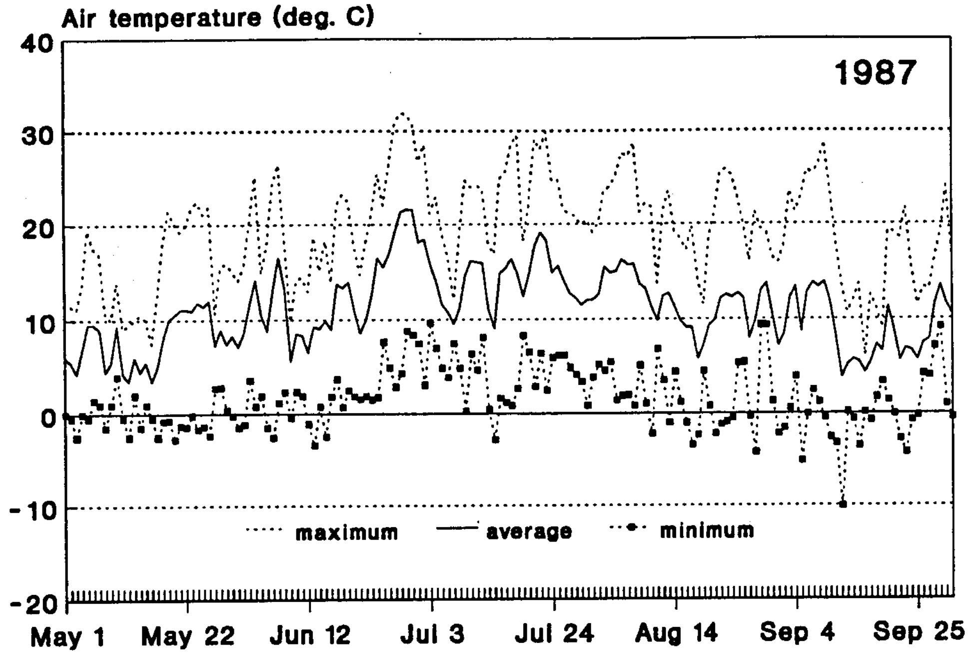


FIGURE 5. Air temperature measured at 20 cm above the ground surface: cumulative degree days above 5°C.



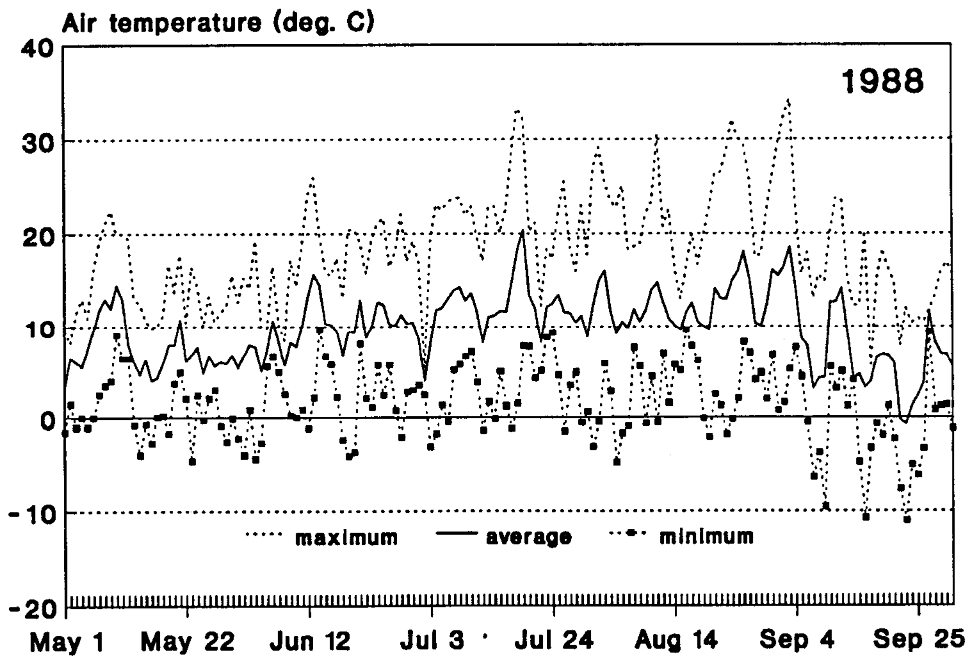


FIGURE 6. Air temperature measured at 20 cm above the ground surface: daily maxima, averages, and minima during the 1987 and 1988 growing seasons.

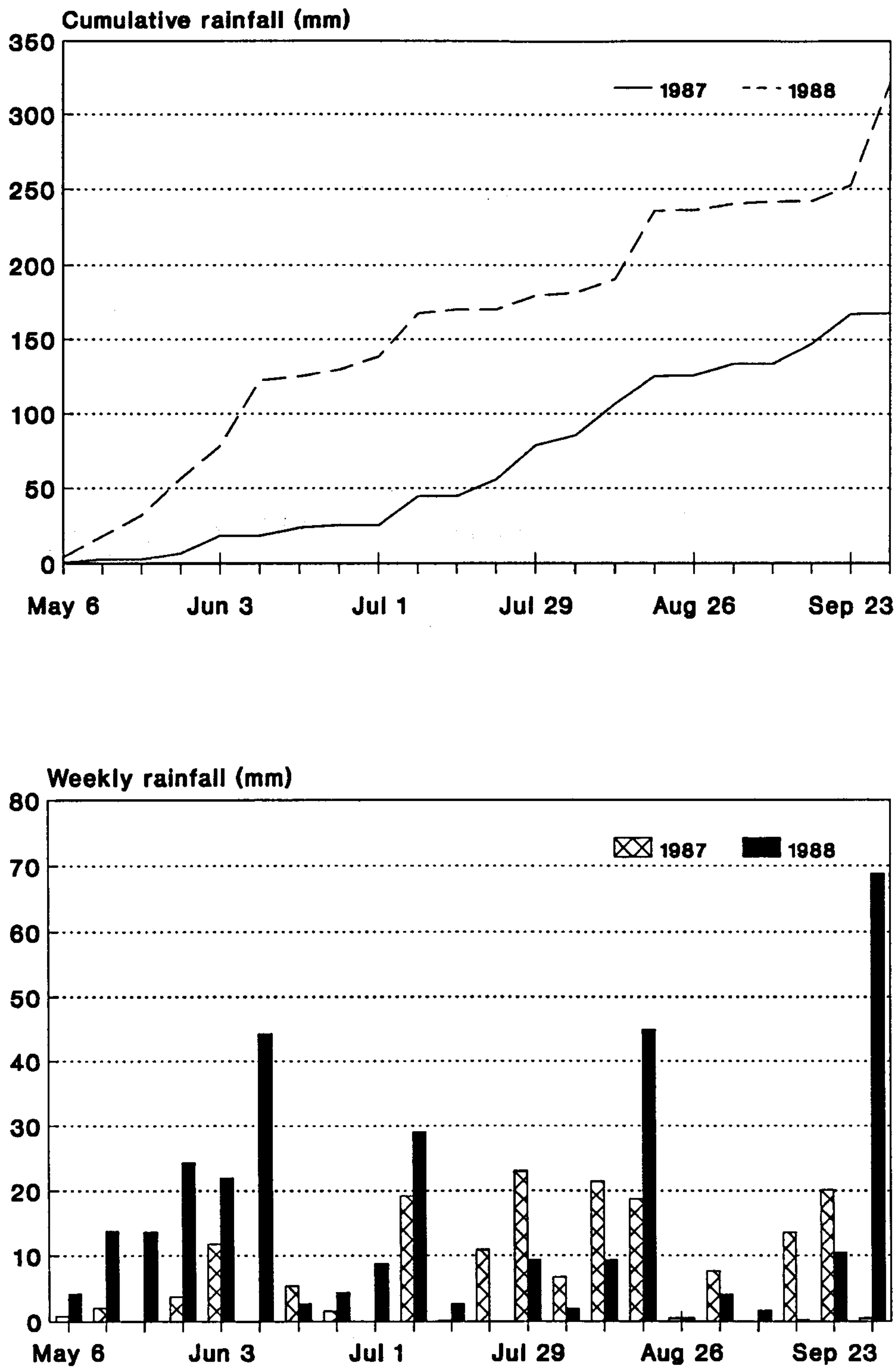


FIGURE 7. Cumulative rainfall and weekly rainfall during 1987 and 1988 growing seasons.

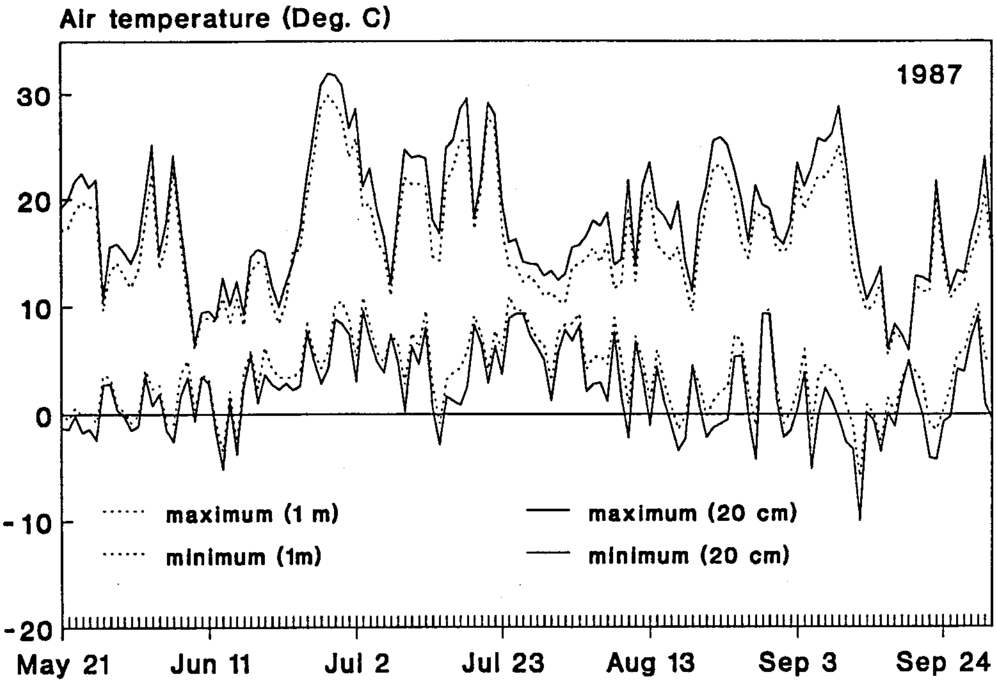


FIGURE 8. Daily maximum and minimum air temperatures at 20 cm and 1 m above the ground surface in 1987.

2.3.2 Soil temperature

There were differences in soil temperature between years, among treatments, and among sites. In some cases there were interactions between site and treatment. The relationships among treatments and among sites and treatments tended to vary from one phase to another.

2.3.2.1 1987 vs. 1988

Figure 9 shows soil temperature phases and daily average soil temperatures at the 10-cm depth in untreated controls and in inverted mounds during the 1987 and 1988 growing seasons. In both years, temperatures in untreated spots rose above 8°C in the spring on June 2 and dropped to and remained below 10°C in the fall during the second week of September. However, in 1988 the warm phase commenced two weeks later than in 1987 and was generally cooler, but persisted two weeks later than in 1987. The relationships among treatments that were observed in 1987 were in general closely mirrored in 1988.

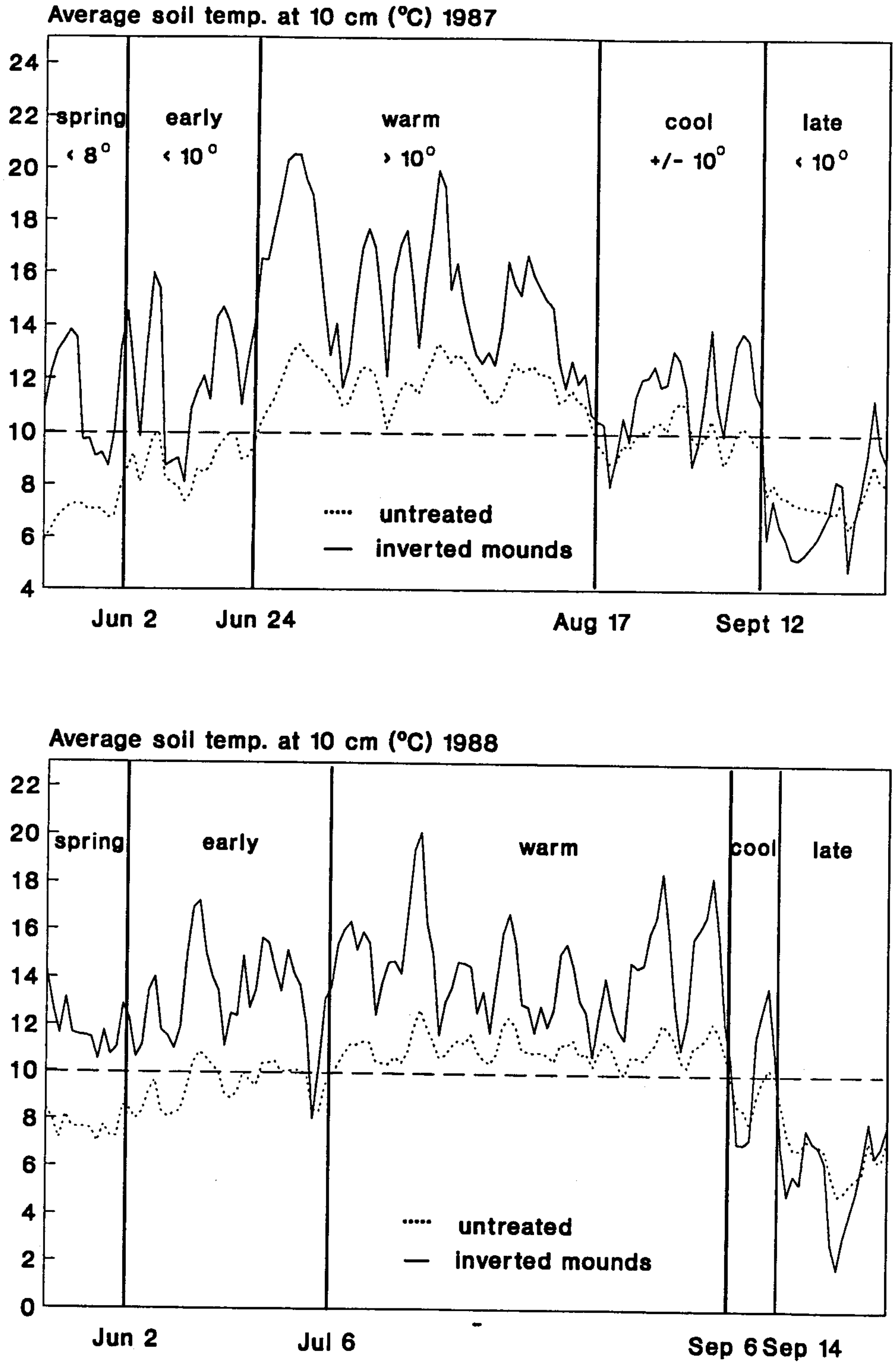


FIGURE 9. Soil temperature phases and daily average soil temperatures at the 10-cm depth in untreated spots and inverted mounds during the 1987 and 1988 growing seasons.

2.3.2.2 Differences among sites

During the warm phase, the fresh site had significantly ($p < 0.05$) higher maximum temperatures than the moist site. The greatest differences were in inverted and scalped spots, which had maximum temperatures more than 3°C higher in the fresh than in the moist site. Minimum temperatures during this period were significantly lower in the fresh site than in the moist site except in untreated and scalped spots.

Figure 10 compares degree hours above 10°C in fresh, moist, and wet sites for those treatments common to each of the sites. Although it was not possible to examine it statistically because of the lack of replication in the wet site, there is an apparent trend of increasing degree hours from wet to moist and fresh sites for all treatments during spring and early phases. For inverted and scalped spots this trend persists through the warm and cool phases. For inverted mounds, however, the trend reversed during the warm phase and for the remainder of the growing season.

2.3.2.3 Relationships among treatments

During spring, early, and warm phases of both years, daily average temperatures were generally highest in inverted mounds and lowest in untreated spots (Fig. 11). During these phases, daily maximum temperatures were frequently 12 - 14°C higher in inverted mounds than in untreated spots (Fig. 12), whereas daily minima were similar or lower by 1 - 3°C. However, during periods of wet overcast weather, soil temperature differences between mounds and untreated spots declined or disappeared (Fig. 13).

Later in the season, average temperatures in inverted mounds were frequently lowest, with daily maximum temperatures only 4° higher on average than in untreated spots, and minimum temperatures 5°C lower than in untreated spots. Differences between inverted mounds with 8-cm capping depths (inv. mnd (8)) and those with 16-cm capping depths (inv. mnd (16)) were not significant ($p < 0.05$) for any of the soil temperature parameters tested.

Throughout the growing season, average and maximum temperatures in mineral mounds and inverted and scalped spots tended to fall between those in inverted mounds and untreated spots. An exception to this was on the wet site where scalped spots were often similar to or slightly cooler than untreated spots. Differences between mineral mounds and inverted spots were generally slight, but this varied with site and year. In the moist site, during both years, average and

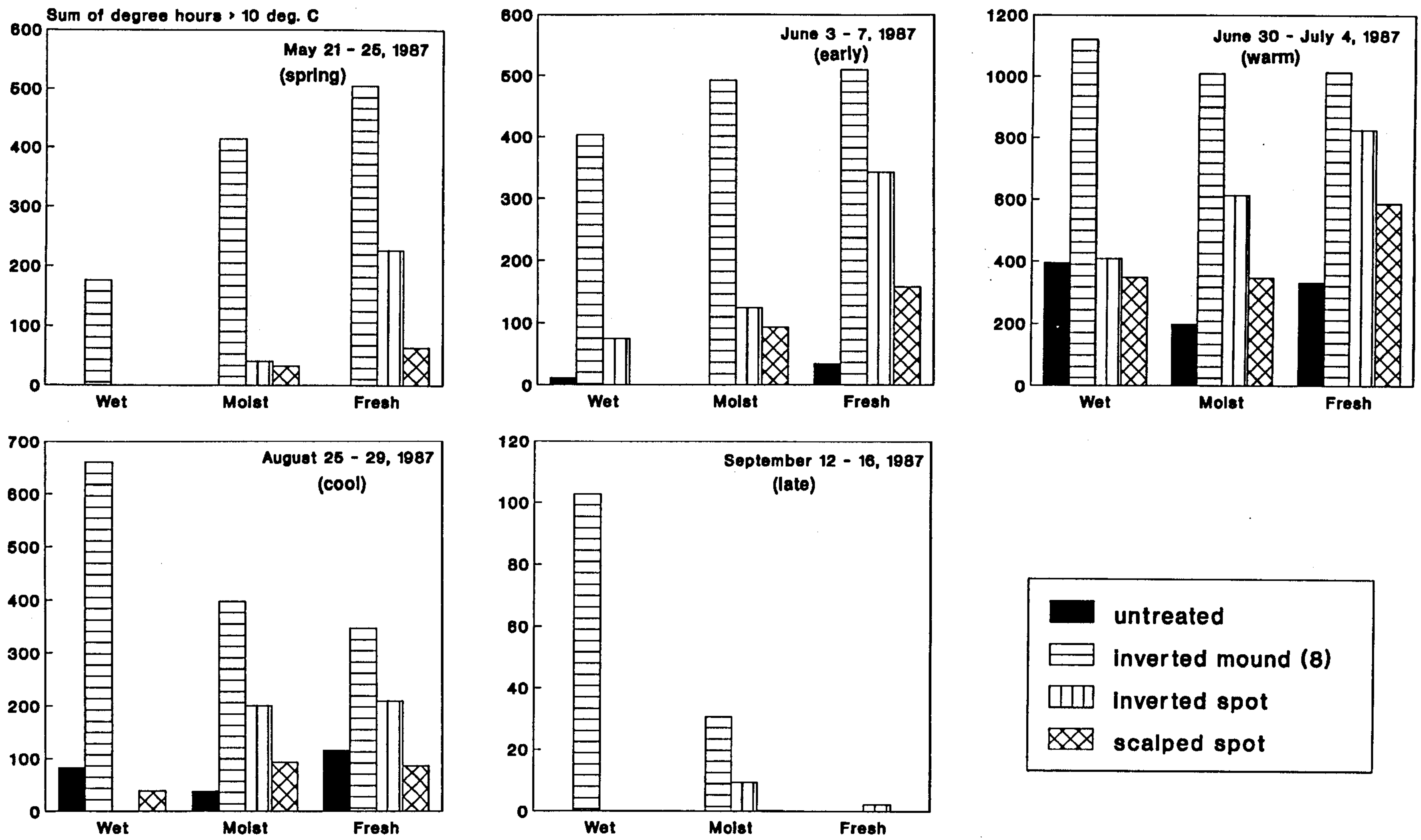


FIGURE 10. Sum of degree hours above 10°C at the 10-cm depth for five-day periods in each phase, for treatments common to wet, moist and fresh sites.

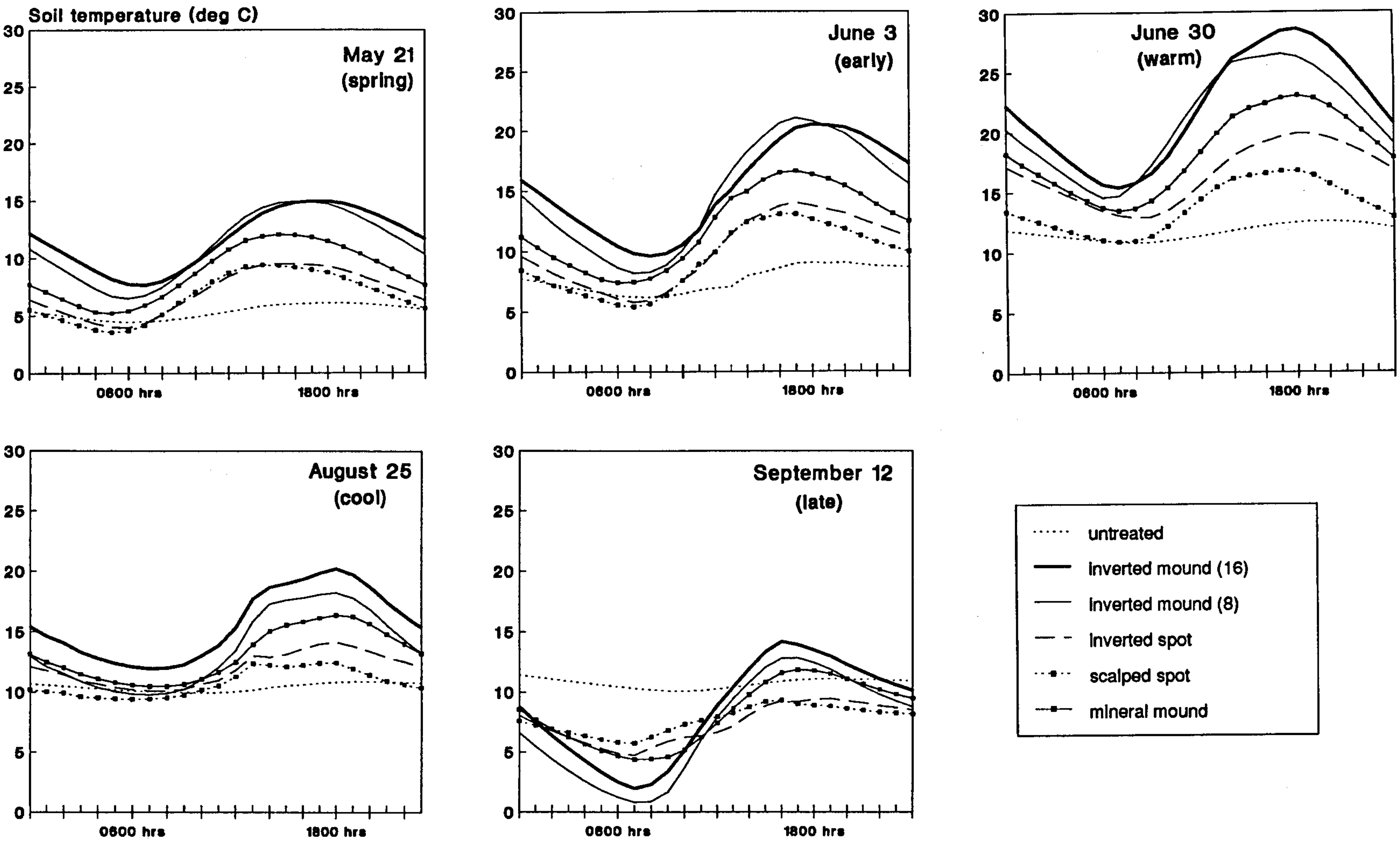


FIGURE 11. Hourly average soil temperatures at the 10-cm depth by treatment for a 24-hour period during each phase (moist site).

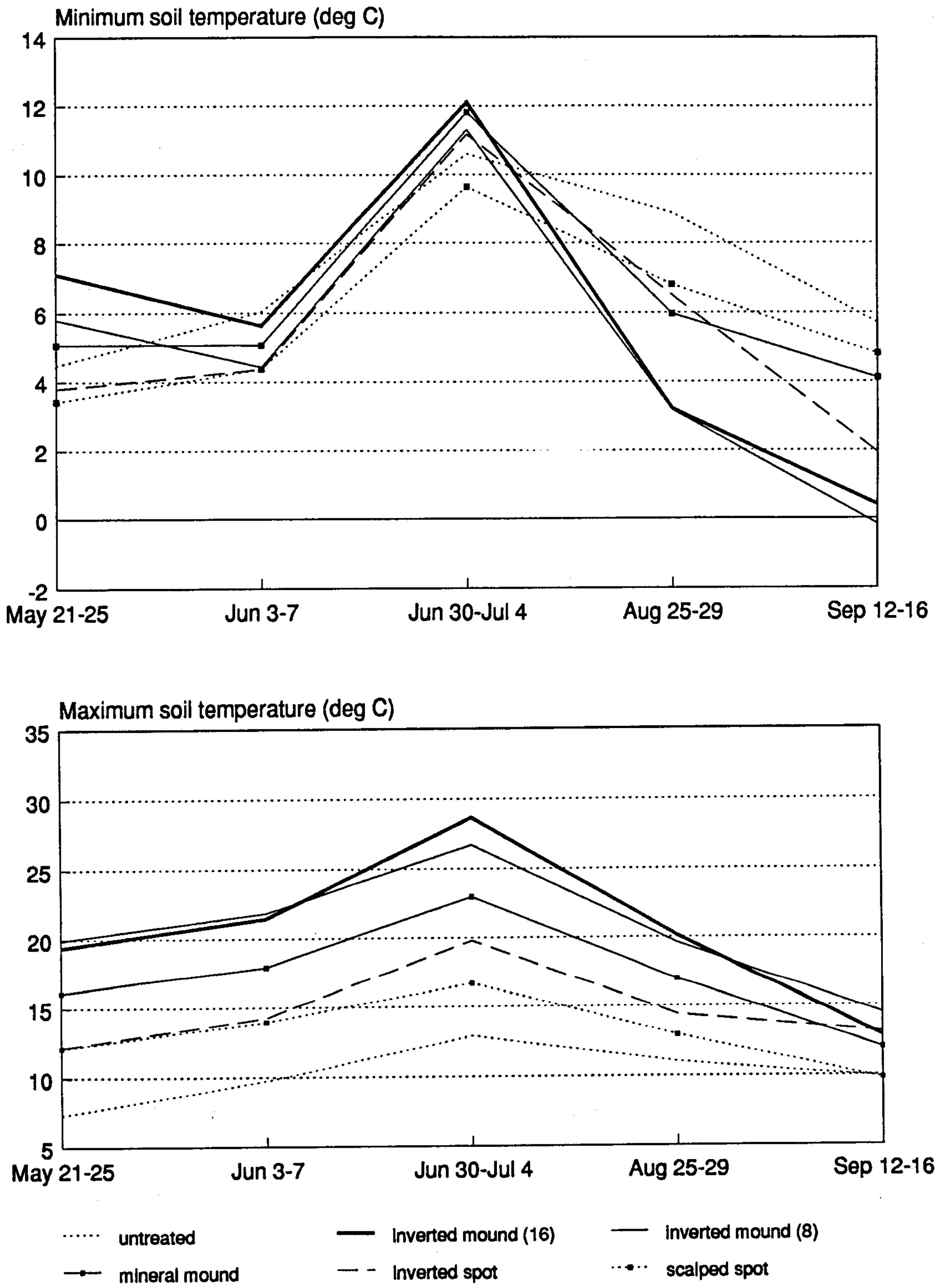


FIGURE 12. Minimum and maximum soil temperatures at the 10-cm depth in 1987, as averages of five-day periods by soil temperature phase (moist site).

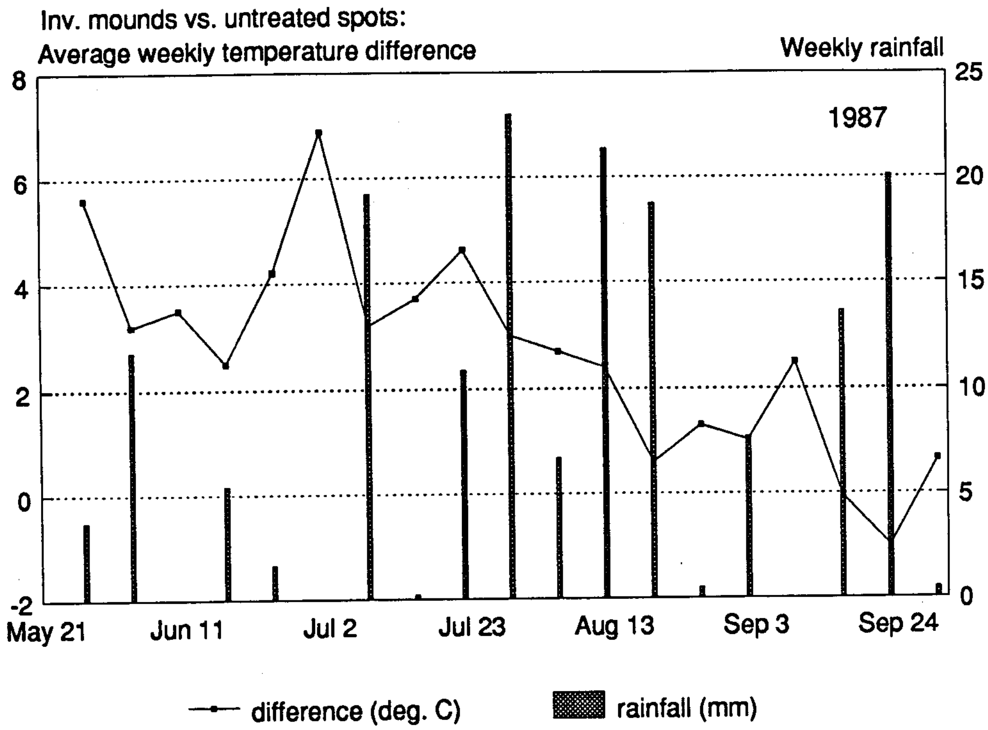


FIGURE 13. Weekly average soil temperature differences between inverted mounds and untreated spots and weekly rainfall during 1987.

maximum temperatures and degree hours greater than 10°C tended to be higher in mineral mounds than in inverted spots. In the fresh site, inverted spots were slightly warmer than the mineral mound during 1987, but not in 1988. During the spring, early, and warm phases these two treatments were generally warmer than scalped spots, although differences were often not statistically significant.

There were substantial differences among treatments during spring, early, and warm phases in degree hour sums (10°C base temperature) (Fig. 14). Temperatures in untreated spots did not rise above 10°C during the spring phase in any of the sites, and during the early phase only briefly in the fresh site. In contrast, sums for inverted mounds during 5-day periods in spring and early phases were 400 - 500 degree hours on moist and fresh sites and somewhat lower on the wet site. Differences among inverted mounds, mineral mounds, and inverted spots varied with site. Sums for scalped spots were not significantly different ($p < 0.05$) from those for untreated spots at any time during the growing season on moist or wet sites, and only during the warm phase on the fresh site.

The most dramatic differences in average hours per day above 8°C between treated and untreated spots occurred early in the season (Fig. 15). Untreated

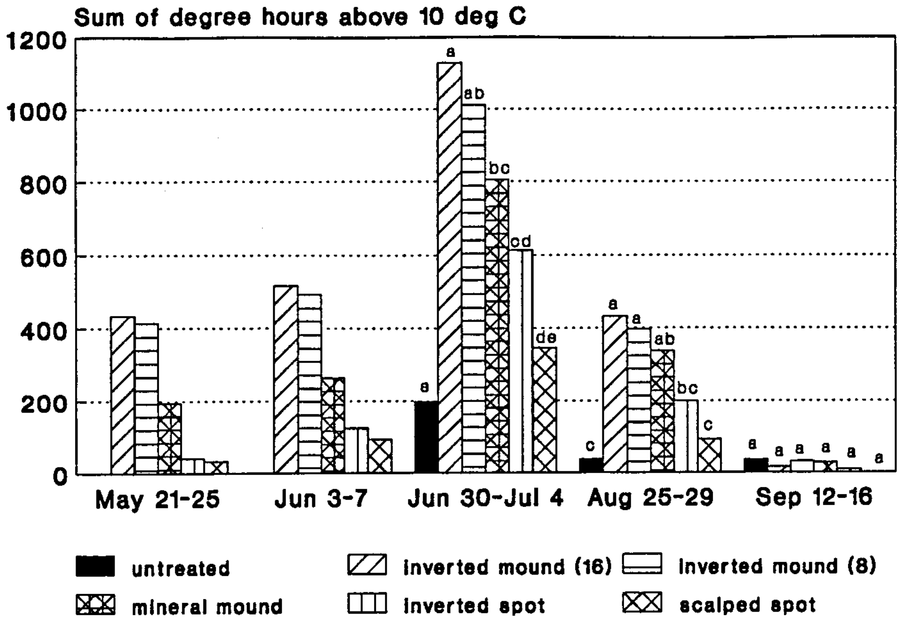


FIGURE 14. Sum of degree hours above 10°C at the 10-cm depth during 5-day periods in each soil temperature phase (moist site).

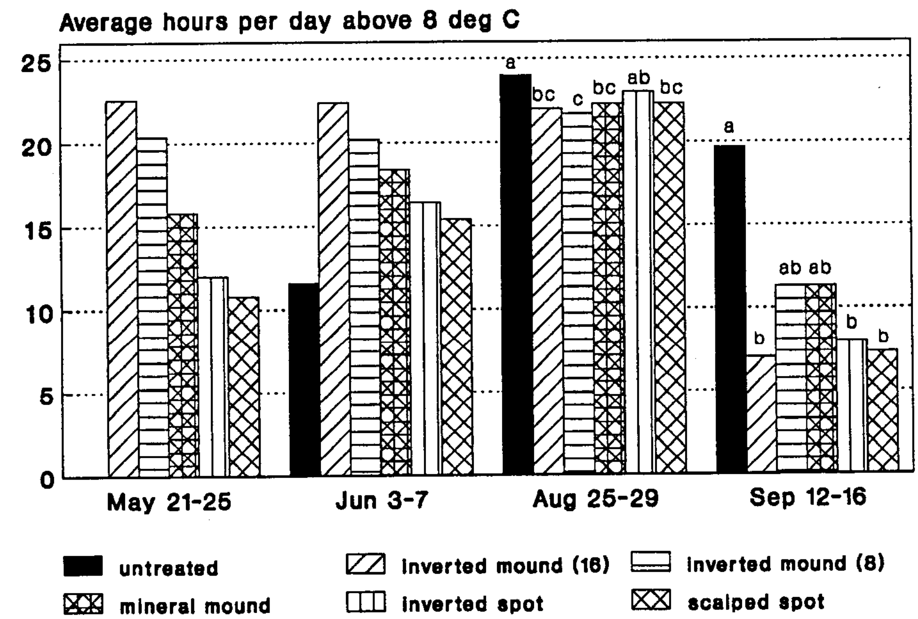


FIGURE 15. Average hours per day at soil temperatures above 8°C for five-day periods during spring, early, cool, and late soil temperature phases, (10-cm depth, moist site).

* Treatments labelled with the same letters are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$). Spring and early phase temperatures in the moist site were not statistically analyzed because measurements were not replicated during those periods.

spots averaged less than 5 hours per day above 8°C during the spring phase irrespective of site, while inverted mounds averaged 17 to 23 hours per day depending on site.

2.3.3 Soil moisture

Data collected in 1987 and 1988 showed similar trends in the response of soil moisture to treatments and sites (Fig. 16). However, most treatments became somewhat drier from mid-July to mid-August in 1988 than they did in 1987 in response to a prolonged period of low rainfall during that period. Although total growing season rainfall was greater in 1988, much of it was concentrated during May and early June, when soil moisture levels tend to be high because of snowmelt.

During both years, inverted mounds became substantially drier than other treatments during much of the growing season. Drying trends began earlier in the season and were more severe in the fresh site relative to moist and wet sites. Inverted mounds in the fresh site dropped to levels below -0.2 MPa by the third week in June of both years, 3 to 4 weeks in advance of those on moist and wet sites.

Site and treatment effects and the interaction of site and treatment were highly significant ($p = 0.0001$) for weeks at greater than -0.5, less than -0.2 and less than -0.3 MPa. Based on two-way ANOVA's within each site, year and year and site interactions had significant effects only on the fresh site. Differences between 1987 and 1988 in the fresh site were found to be primarily associated with the mineral mound treatment, which became substantially drier in 1988 than it had been in 1987.

Table 7 shows the number of weekly observations of soil water potentials at greater than -0.05, less than -0.2, and less than -0.3 MPa by site and treatment. Table 8 shows the results of contrasts of the same data. Irrespective of site, inverted mounds became substantially drier than other treatments ($p \leq 0.003$). In moist and wet sites, only inverted mounds became dry for significant periods during the growing season. In the fresh site, inverted mounds, inverted spots, and, in 1988, mineral mounds were below -0.2 MPa for more than six of the weekly observations.

Results for scalped spots were not significantly different from those in untreated spots in any of the sites. Inverted mounds were significantly drier than mineral mounds in both moist and fresh sites.

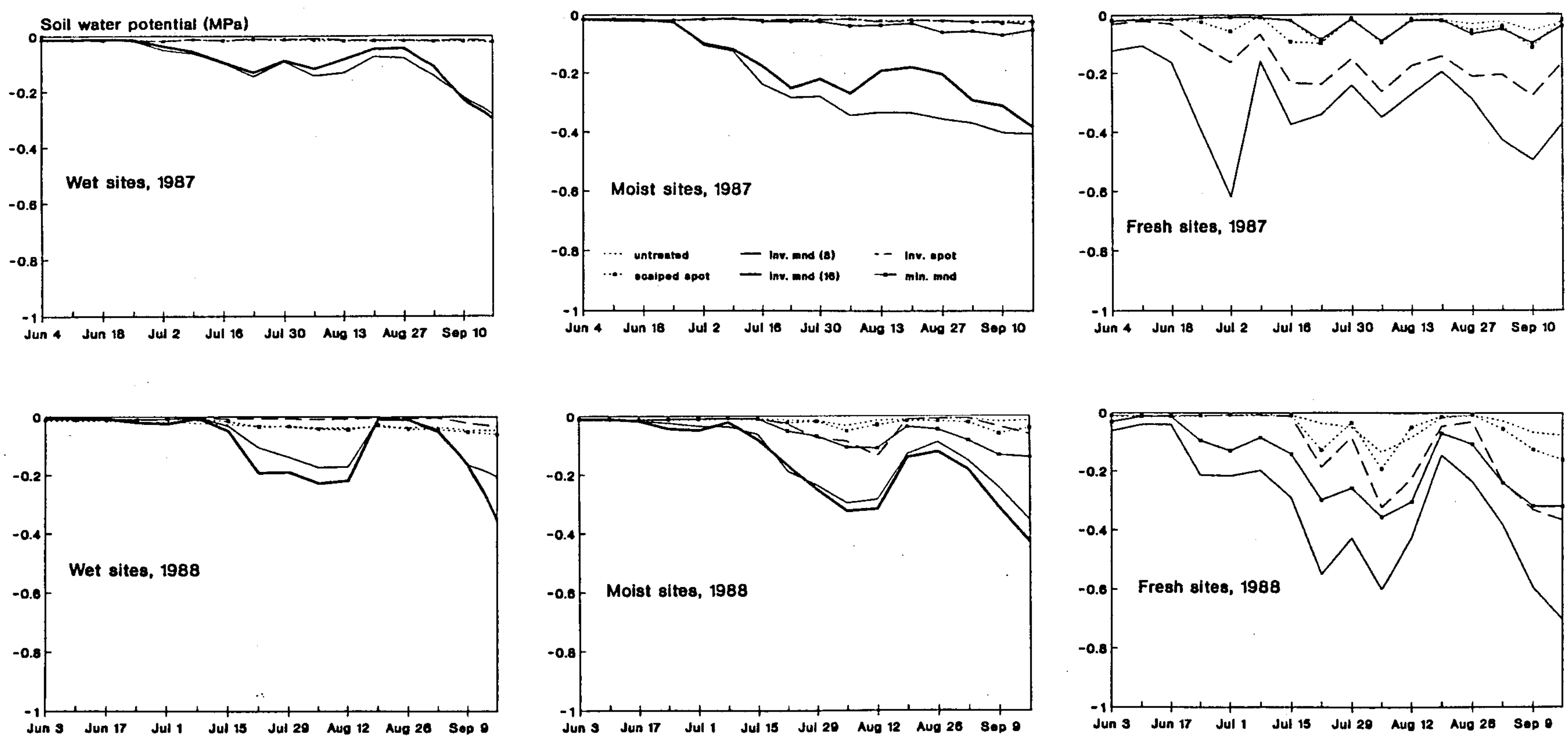


FIGURE 16. Soil water potential at the 10 to 12-cm depth, by site and treatment, June to September 1987 and 1988.

TABLE 7. Average number of observations of soil water potential at greater than -0.05, less than -0.2, and less than -0.3 MPa at the 10 to 12-cm depth, by site and treatment, out of 16 weekly observations between early June and mid-September, 1987 and 1988.

Site	Year	Treatment	Number of weekly observations at: > -0.05 MPa		< -0.2 MPa		< -0.3 MPa	
wet	1987, 1988	inv. mound (16)	10.7	c	2.9	a	2.0	a
		inv. mound (8)	11.6	bc	1.9	a	0.7	ab
		inv. in place	15.9	a	0.0	b	0.0	b
		scalped	14.0	ab	0.0	b	0.0	a
		untreated	15.9	a	0.0	b	0.0	a
moist	1987, 1988	inv. mound (16)	8.4	c	4.9	a	3.1	a
		inv. mound (8)	7.9	c	6.5	a	5.2	a
		min. mound	12.3	b	1.1	b	0.3	b
		inv. in place	15.8	a	0.1	b	0.1	b
		scalped	15.3	ab	0.1	b	0.0	b
		untreated	15.9	a	0.0	b	0.0	b
fresh	1987	inv. mound (8)	3.1	b	10.6	a	6.7	ab
		min. mound	13.6	a	0.4	c	0.1	b
		inv. in place	5.9	b	6.4	ab	3.4	abc
		scalped	12.9	a	0.0	c	0.0	c
		untreated	14.0	a	0.0	c	0.0	c
	1988	inv. mound (8)	4.0	b	11.0	a	8.3	a
		min. mound	5.3	b	7.7	a	4.4	abc
		inv. in place	7.3	a	6.7	a	4.1	abc
		scalped	12.1	a	2.0	bc	0.0	c
		untreated	12.9	a	0.7	bc	0.0	c

* 1987 and 1988 data were pooled for wet and moist sites because differences between the two years were not significant. Within sites, means followed by the same letter are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$).

The inv. mnd (8) treatment was not significantly different from the inv. mnd (16) in terms of the number of observations of water potential greater than -0.05 and less than -0.2 MPa, but there were significant differences among sites and between years in the number of observations of water potentials below -0.3 MPa (Fig. 16). The greatest differences observed were in the moist site after mid-July in 1987, where the inv. mnd (8) became significantly drier than the inv. mnd (16). The same trend was observed that year in the wet site, however differences between the two were slight. In 1988, the trend reversed on both sites, and differences between the two treatments were less marked in the moist site.

TABLE 8. Contrasts of the number of weekly observations of soil water potential at greater than -0.05 (moist), less than -0.2 (slightly dry), and less than -0.3 MPa (moderately dry).

Contrast	Df	Number of weekly observations at: > -0.05	< -0.2	< -0.3 MPa
		--------	Pr > F	--------
Wet site				
scalped spots vs. untreated	1	0.1158	1.0000	1.0000
8 vs. 16-cm inverted mounds	1	0.4281	0.1414	0.0120
inverted mounds vs. other treatments	1	0.0001	0.0001	0.0003
untreated vs. treated	1	0.0034	0.0256	0.0884
Moist site				
scalped spots vs. untreated	1	0.5621	0.9400	1.0000
8 vs. 16-cm inverted mounds	1	0.6062	0.1011	0.0132
inverted mound vs. other treatments	1	0.0001	0.0001	0.0001
inverted spots vs. mineral mounds	1	0.0022	0.2941	0.8000
inverted mounds vs. mineral mounds	1	0.0001	0.0001	0.0001
Fresh site				
untreated vs. treated	1	0.0001	0.0001	0.0001
all treatments (87 vs. 88)	1	0.8832	0.2705	0.4038
mineral mounds (87 vs. 88)	1	0.0001	0.0001	0.0025
scalped spots vs. untreated	1	0.3695	0.4967	1.0000
inverted mounds vs. other treatments	1	0.0001	0.0001	0.0001
inverted mounds vs. mineral mounds	1	0.0001	0.0001	0.0001
inverted spots vs. mineral mound (88)	1	0.1736	0.5011	0.8342
inverted vs. mineral mound (88)	1	0.3795	0.0299	0.0062

2.4 Discussion

The response of soil moisture and temperature regimes to inverted mound and scalped spot treatments were similar to those observed by Bassman (1989) in a more southerly but higher elevation biogeoclimatic zone (ESSF) in the British Columbia interior. Draper *et al.* (1985) also reported large increases in growing season soil temperature and decreases in soil water potential in inverted mounds in a wetter subzone of the SBS Zone. Based on studies in dry to fresh sites in Sweden, Örlander (1986) reported increased soil temperatures and decreased soil moisture in response to treatments in the order: inverted mound > mineral mound > scarified patch (scalped spot) > no treatment.

Daytime and average soil temperatures in mounds were highest relative to those in untreated spots during dry sunny weather. Differences declined during wet overcast weather and also with decreasing air temperature and day-length toward the end of the growing season. Similar observations were made by Örlander (1986) and Bassman (1989).

Soil temperature trends appeared to be closely tied to soil moisture levels. Early in the season and during warm sunny weather, daytime soil temperatures generally increased with decreasing soil moisture levels. In addition there was a trend throughout the growing season to greater diurnal fluctuations in soil temperature with decreasing soil moisture. These effects were anticipated, since water has a high volumetric heat capacity relative to mineral particles, organic matter and air (Hillel 1982), and consequently rates of both soil warming and cooling in response to temperature changes at the surface decrease with increasing moisture content.

Soil temperatures in inverted mounds were cooler in wet sites relative to moist and fresh sites up to the middle of June, but tended to be warmer in wet sites later in the season. This observation is also likely related to soil moisture levels, which were slower to drop in the wet site due to the shallowness of the perched water table in that site. Abundant seepage was observed in the wet site within 20 cm of the soil surface up to late June, after which it subsided to the 30 to 35-cm depth.

Soil moisture and temperature were clearly influenced by site factors, in particular soil drainage, and by treatment characteristics, primarily microsite elevation and surface area. Microsite elevation was likely of greatest importance in moist and wet sites early in the growing season when water table levels were at their peak. The larger surface area associated with mounded treatments would be expected to absorb greater amounts of heat from solar radiation, and also loose greater amounts of moisture as evaporation. In terms of height above the undisturbed forest floor surface and total surface area, treatments ranked as follows: inv. mnd (16) > inv. mnd (8) > inverted spot = mineral mound > untreated spot > scalped spot. Within sites, soil moisture and temperature levels tended to follow the same order, with a few exceptions. Average temperatures in scalped spots were somewhat lower than in untreated spots in wet sites early in the season, however, scalped spots were frequently slightly warmer than untreated spots, particularly in the fresh site. This can be attributed to the fact that the thermal conductivity of mineral soil materials is close to ten times greater than that of organic matter (Hillel 1982). Under moist conditions, thermal diffusivity through the forest floor will still be relatively low, but for a different reason. Because organic matter has a high moisture storage capacity, a wet forest floor layer will tend to have a high volumetric heat capacity.

Results indicated a far greater warming effect after forest floor removal in the fresh site than under moister conditions in moist and wet sites. Dobbs and McMinn (1977), McMinn (1982), Örlander (1986a) and Bassman (1989) all observed some degree of soil warming following forest floor removal. In Bassman's study, which took place on a fresh - moist high elavation site, temperature differences between controls and scarified patches were greatest at the 5-cm depth and were extremely slight at 12 cm. Örlander observed significant temperature increases at the 10-cm depth on sites with dry to fresh moisture regimes.

The response of soil moisture levels in inv. mnd (8) relative to inv. mnd (16) treatments during 1988 appeared to contradict 1987 results. The apparent contradiction can, however, be explained in the light of differences in patterns of rainfall observed during the two years, and to material differences between the two treatments at the sampling depth. In the inv. mnd (8) the 12-cm depth lies within the over-turned mat of forest floor materials, whereas in the inv. mnd (16) it lies within the capping material, approximately 4 cm above the organic layer. In 1988 the months of May and June were relatively moist, but were followed by a prolonged period of low rainfall from mid-July to mid-August. By late July, soil water potentials at the 10 to 12-cm depth had dropped below -0.2 MPa in both inverted mound treatments. The inv. mnd (16) became slightly drier than the inv. mnd (8) during this period in both wet and moist sites, which may be attributed to greater evaporation from the larger mound because of its greater surface area, or larger amounts of residual moisture being stored in the organic layer within the inv. mnd (8) relative to the mineral soil capping of the inv. mnd (16). A period of very heavy rainfall in the third week of August returned both treatments close to the -0.1 MPa level.

The distribution of rainfall during 1987 was quite different. In contrast, the months of May and June, 1987 were relatively dry, resulting in low soil moisture levels in both treatments by late June. When rainfall increased later in July and August, soil moisture levels at the 10 to 12-cm depth in the inv. mnd (16) treatment responded rapidly with slight increases, while moisture levels at the same depth in the inv. mnd (8) treatment remained low. This is likely due to greater hydraulic conductivity within the 0 - 12-cm layer in the inv. mnd (16). Once the organic mat in the inv. mnd (8) treatment became dry in June, it appeared to resist re-wetting in spite of the addition of moderate amounts of moisture at the surface later in July and August. Low hydraulic conductivity at the mineral soil - organic layer interface might simply be a function of lower unsaturated hydraulic conductivity in the organic layer relative to that in the mineral soil (Örlander and Due 1986), or differences in pore-size distribution between the two materials (ie. larger pores in the organic matter) (Hillel 1982), and/or the development of hydrophobicity in the organic materials due to prolonged drying and warm temperatures.

The greater responsiveness of soil moisture levels in the inv. mnd (8) in the fresh site to inputs of precipitation during July and August, 1987 may have been caused by the relative thinness of the forest floor in that site, and tendency for it to have been disturbed and intermixed with mineral materials to a greater extent during mound construction.

3 EFFECTS OF MICROSITE SOIL TEMPERATURE ON NITROGEN MINERALIZATION

3.1 Introduction

Nitrogen is present in soils almost exclusively in organic forms. Its availability for plant uptake depends on the decomposition of organic matter by soil microorganisms, resulting in the release of mineral nitrogen (N) in the form of ammonium (NH_4^+). Amounts of organic matter present, and rates of organic matter decomposition are therefore closely linked to the availability of soil N, and to overall site nutrition, because N is often limiting to productivity in forest ecosystems.

The heterotrophic organisms involved in decomposition use the organic substrate both as an energy source (carbon) and for the synthesis of new biomass. Only when the N requirements of the decomposer organisms have been met is the excess released into the soil (Rosswall 1982). Rates of N mineralization therefore depend on the relative proportions of carbon (C) and N in the material (C:N ratio), and on the C:N ratio of the organisms themselves. Other physical and chemical characteristics of the organic substrate are important as well. For example, rates of decomposition of forest litter have been shown to decrease with increasing lignin content (Berg and Staaf 1980), because of the resistance of lignin to microbial attack. Melillo *et al.* (1982) further suggested that amounts of N immobilized during organic matter decomposition increase with initial lignin content.

The soil environment is a complex and dynamic system in which a large number of processes are constantly in competion for mineral forms of N (NH_4^+, NO_3^-, and NO_2^-), among them absorption by plant roots, assimilation by microorganisms, oxidation by nitrifying bacteria, reduction by denitrifying bacteria, attraction to exhange surfaces, and fixation by clay minerals (Rosswall 1982). Assimilation by microorganisms removes N temporarily from the available pool, however ultimately it returns to a mineral form as the microbial cells die and decompose. Mineralization also occurs when excess N is released during the predation of microorganisms by soil animals such as protozoa and nematodes (Anderson *et al.* 1981).

Environmental factors indirectly affect rates of N mineralization through their influence on microbial activities. According to Alexander (1972), a wide variety of organisms, capable of tolerating a wide range of environmental conditions, are able to decompose organic materials containing N, so some activity may be assumed to be taking place in soil virtually at all times, though under some circumstances rates may be extremely low. Factors such as soil pH, moisture, temperature, and the supply of inorganic nutrients control rates of microbial activity and proliferation. Soil pH levels close to neutral are generally regarded as being optimal for the process of N mineralization (Alexander 1972). Rates of aerobic microbial activity are extremely slow at very low moisture levels, and increase with increasing moisture content to an optimal level when water-filled pore space approaches 60% (Linn and Doran 1984).

Soil temperature is important in that it is one of the factors controlling the growth of microorganisms, and it controls the activity of several of the enzymes that catalyze biochemical steps in the mineralization process (Alexander 1972). Between 0°C, at which no mineralization occurs, and the optimal range for the process (40-60°C), rates of mineralization increase with increasing temperature, all other factors being equal. Powers (1990) measured N mineralization in the field along an altitudinal gradient, and found a close relationship between soil temperature and the percentage of total N mineralized per year under anaerobic conditions. Under laboratory conditions, Theodorou and Bowen (1983) observed linear increases in N mineralization in a *Pinus radiata* forest soil with increasing temperature from 5°C to 25°C.

Frazer *et al.* (1990) found evidence to suggest that increased rates of N mineralization following clearcutting were related to increased soil temperatures and soil moisture. In a study in Florida, Burger and Pritchett (1984) concluded that although N mineralization potentials, based on laboratory incubations, were decreased following clearcutting and intensive site preparation (blading, discing, and bedding), actual rates under field conditions were likely to be greater than in untreated soils because of higher soil temperatures and more favorable moisture conditions following site preparation.

Mechanical site preparation treatments such as mounding have been shown in this study and others (eg. Draper *et al.* 1985; Bassman 1989) to result in substantial increases in growing season soil temperatures. This component of the study was designed to determine whether these mechanically-induced increases in soil temperature are sufficient to affect rates of N mineralization in the climatic context of the SBS Zone, and if so, how the chemical properties of the soil substrate affect the response of N mineralization rates to increased soil temperatures. Two experiments involving the measurement of rates of N mineralization under field conditions were conducted in 1987.

3.2 Methods

3.2.1 Experiment "A"

Five pairs of mounded and adjacent untreated spots were selected in fresh, moist, and wet study plots. On July 1, two soil cores, 4 cm in diameter and 15 cm in depth were taken from each mounded and untreated spot. Subsamples were taken for the determination of moisture content and NH_4^+ and NO_3^- concentrations, and the remaining material was enclosed in a sealed polyethylene bag (Westermann and Crothers 1980). One core per pair was returned to its original location, and the other placed in the adjacent mounded or untreated spot. On September 15, following a period of 11 weeks, samples were retrieved. Each was well mixed and then divided into two subsamples, one to be extracted for $NH_4^+$and NO_3^- analysis, and the other used for the determination of moisture content. Soil cores were taken from the 0 - 15 cm layer from each mounded and untreated spot, air dried, ground, and sieved to < 2 mm. Soil pH was determined on 1:1 soil and water suspensions using a pH meter. Following semi-micro Kjeldahl digestion, total N was determined colorimetrically using a Technicon Autoanalyzer. Mineralizable N was estimated following a two-week anaerobic incubation at 30°C (Waring and Bremner 1964) by colorimetric analysis for NH_4^+. Total C was determined using a LECO Carbon Analyser.

Samples taken for NH_4^+ and NO_3^- analysis in July and September were kept under refrigeration until they were extracted. Within 48 hours, samples were extracted in a 0.5 N solution of K_2SO_4, shaken thoroughly, left to equilibrate, then filtered. The supernatant was analyzed for concentrations of NH_4^+ and NO_3^- using a Technicon Autoanalyser.

Soil concentrations of NH_4^+-N, NO_3^--N, and the sum of NH_4^+-N and NO_3^--N (N_{inorg}) were calculated based on concentrations in extracts and soil moisture content. Differences between pre-incubation levels and post-incubation levels were calculated for NH_4^+, NO_3^-, and N-inorg.

The data were analyzed as a randomized block design, with separate ANOVA's for each site (Table 9). Tukey's Studentized Range (HSD) test ($p < 0.05$) was used to test the significance of differences among treatments. Contrasts were used to test the significance of effects of material source and location of incubation, and the significance of differences between N concentrations in materials from untreated spots and mounds incubated in their original locations. T-tests for pair-wise comparisons (described by SAS Institute 1988) were used to test the significance of differences in levels of inorganic N at the beginning and end of the incubation period, by material source and location.

TABLE 9. ANOVA and contrasts for inorganic N levels, Experiment "A".

Source of variation	Df
Blocks	4
Treatments	3
Error	12
Total	19
<u>Contrasts</u>	
Source of material (mounds vs. untreated spots)	
Location of incubation (mounds vs. untreated spots)	
Materials from mounded vs. untreated spots, incubated in place	

Data from the chemical analysis of air-dried samples were analyzed as a split plot design to test effects of site and treatment on chemical properties (Table 10). Tukey's Studentized Range (HSD) test was used to test for the significance of differences among sites. T-tests were used to test the significance of differences between materials from mounds and untreated spots, by site.

TABLE 10. ANOVA for soil chemical properties, Experiment "A".

Source of variation	Df
<u>Mainplot:</u>	
Sites	2
Blocks (Sites)	4
Error	8
<u>Split plots:</u>	
Treatments	1
Site * Treatment	2
Error	12
Total	29

3.2.2 Experiment "B"

Based on soil temperatures observed in May and June, 1987, degree hour sums (5°C base temperature) were calculated for each combination of site and mechanical treatment in fresh and moist sites. From among the 11 available combinations, six microsites were selected to provide a wide range of thermal regimes. In order of decreasing degree hour sums the microsites chosen were:

1. inverted mound (16 cm capping) (moist site)
2. inverted mound (8 cm capping) (fresh site)
3. inverted spot (fresh site)
4. scalped spot (fresh site)
5. scalped spot (moist site)
6. untreated spot (moist site)

Approximately 5 l of a standard mineral soil material, visually judged to have a relatively high organic matter content and very low coarse fragment content, was collected from the study site. In the lab, the material was mixed thoroughly and all visible fragments of root and other organic debris and coarse fragments were removed. Field moist 30-g subsamples (30 in total) were weighed and placed in polyethlyene bags, which were then sealed and taken to the study site in a cooler. Five subsamples were taken for the determination of moisture content, and for extraction and subsequent NH_4^+ and NO_3^- determination, as previously described for Experiment "A". Approximately 1 l of the soil was air dried, and subsamples were analyzed for total N, total C, pH (in water), and mineralizable N.

At the study site, soil cores (15 cm in depth) were removed from five randomly selected spots for each of the 6 site*treatment combinations, and replaced by the sealed bags of standard material. These were left in place for 11 weeks (July 1 - September 15), and then returned to the lab for the determination of moisture content and extraction and analysis for concentrations of NH_4^+ and NO_3^-.

Soil concentrations of NH_4^+, NO_3^-, and N-inorg were calculated, as well as differences between pre- and post-incubation concentrations. Data were analyzed as a completely randomized design (Table 11) and the significance of differences among groups of microsites and individual microsites were assessed using contrasts and Tukey's Studentized Range (HSD) tests.

TABLE 11. ANOVA for Experiment"B".

Source of variation	Df
Microsite	5
Error	24
Total	29

Degree hour sums (5°C base temperature) for the period July 1 to September 15, 1987 were calculated for each of the six microsites used in Experiment "B" (Honeycutt *et al.* 1988). Regression analysis was used to test the relationship between degree hours sums and changes in inorganic N concentrations during incubations.

3.3 Results

3.3.1 Experiment "A"

Chemical analyses of air-dried samples revealed differences among sites and between mounded and untreated spots in total and mineralizable N (Min. N), total C, and pH (Table 12). Total N and C and Min. N concentrations were

TABLE 12. Chemical analysis of air-dried samples from each site and microsite treatment (Experiment "A"), and of the standard soil material used in Experiment "B".

Site	treatment	Min. N (mg/kg)	N (%)	Min. N/ Total N	C (%)	C:N	pH (H_2O)
wet	untreated	245 *	1.20	0.020	41.4	34	5.8
wet	mounded	185	0.99	0.019	31.0	31	5.8
moist	untreated	294 *	1.20 *	0.025	32.9 *	27 *	6.2 *
moist	mounded	148	0.77	0.019	17.2	22	6.4
fresh	untreated	20 *	0.13 *	0.015	4.3 *	33	4.7
fresh	mounded	33	0.19	0.017	7.2	38	4.5
Experiment "B" std.		28	0.47	0.006	8.3	18	6.3

* Indicates significant difference between mounds and untreated spots within sites ($p < 0.05$).

greatest in the wet site and in the untreated spot in the moist site, and lowest inthe untreated spot in the fresh site. The ratio of C:N was significantly ($p < 0.05$) lower and soil pH was significantly higher in materials from the moist site relative to wet and fresh sites. Overall, C:N was lowest in the moist site mound, and highest in the fresh site mound.

Table 13 shows average concentrations of inorganic N before and after incubations and differences, by site and treatment. The same data, grouped by material source and the location of the incubation is shown in Figure 17. Results of contrasts are given in Table 14.

Of the three sites, the wet site had the highest concentrations of inorganic N at the beginning of the incubation period, followed in declining order by moist and fresh sites (Fig. 18). During incubations, concentrations of NH_4^+ declined while NO_3^- concentrations increased significantly ($p < 0.05$), suggesting that nitrification occurred in all materials and locations, with the exception of mounds in the fresh site (Table 13). Apart from this one common trend, changes in inorganic N during incubations followed distinct patterns in each of the sites.

3.3.1.1 Wet site

Contrasts indicated that the location of the incubation had a highly significant effect ($p = 0.0055$) on NO_3^- concentrations following incubations in the wet site, whereas the source of materials did not (Table 14). Although there were net decreases in both NO_3^- and N-inorg in mounded locations, concentrations increased (although not significantly for N_{inorg}) in untreated locations. The contrast of untreated vs. mounded spots (both materials incubated in place) indicated significantly ($p = 0.0049$) greater increases in NO_3^- in untreated than in mounded spots.

3.3.1.2 Moist site

Here results were quite different. In the moist site the source of material did have significant effects on NH_4^+ (before incubation, after, and differences), NO_3^- (after incubation and difference), and N_{inorg} (before and after incubation). Material from untreated spots showed higher inorganic N concentrations in each case where contrasts were significant, but the increase in inorganic N in 'untreated' materials in September was slightly lower on average than that observed in material from mounds. Location of incubation had a significant ($p = 0.0163$) effect on post-incubation NH_4^+ concentrations (higher for untreated spots than

TABLE 13. Average inorganic N concentrations at the beginning (July) and end (Sept.) of the incubation period, the difference (Diff.), and soil moisture content at the end of incubations, by site and treatment (Experiment "A").

Site	Treatment	July	Sept.	Diff.	July	Sept.	Diff.	July	Sept.	Diff.	Sept.
			NH_4^+-N			NO_3^--N			N_{inorg}		H_2O
	(material - location)	-----	mg/kg	-----	-----	mg/kg	-----	-----	mg/kg	-----	%
wet	untreated - untreated	108.1 a[1]	9.9 a	-98.2 a	25.2 a	157.5 a	132.3 a	133.3 a	167.4 a	34.1 a	372
wet	mound - untreated	90.5 a	10.8 a	-79.7 a	42.8 a	127.0 a	84.1 ab	133.3 a	137.8 a	4.4 a	228
wet	untreated - mound	103.2 a	38.2 a	73.2 a	29.1 a	73.2 a	44.1 ab	132.3 a	111.4 a	-20.9 a	350
wet	mound - mound	85.4 a	15.3 a	-70.1 a	40.3 a	70.4 a	30.1 b	125.7 a	85.7 a	-40.1 a	156
moist	untreated - untreated	76.2 a	18.5 a	-57.7 a	18.2 a	82.0 a	63.8 ab	94.4 a	100.5 ab	6.1 a	224
moist	mound - untreated	29.5 a	6.8 c	-22.7 a	10.7 a	52.6 a	41.9 b	40.2 a	59.4 b	19.2 a	92
moist	untreated - mound	58.9 a	12.9 b	-46.1 a	12.1 a	97.6 a	85.5 a	71.0 a	110.4 a	39.5 a	226
moist	mound - mound	30.4 a	5.7 c	-24.7 a	9.0 a	64.2 a	55.1 ab	39.4 a	69.8 ab	30.4 a	84
fresh	untreated - untreated	10.2 a	5.1 a	-5.0 a	5.1 a	16.4 ab	11.3 ab	15.3 a	21.5 ab	6.2 ab	30
fresh	mound - untreated	14.4 a	11.2 a	-3.2 a	11.4 a	25.5 a	14.1 a	25.8 a	36.7 a	10.9 a	38
fresh	untreated - mound	7.2 a	3.8 a	-3.5 a	4.8 a	8.7 b	3.9 ab	12.0 a	12.4 b	0.4 ab	18
fresh	mound - mound	13.8 a	4.5 a	-9.3 a	13.1 a	7.2 b	-5.8 b	26.9 a	11.7 b	-15.1 b	24

[1]Within sites, treatment means followed by the same letter are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$).

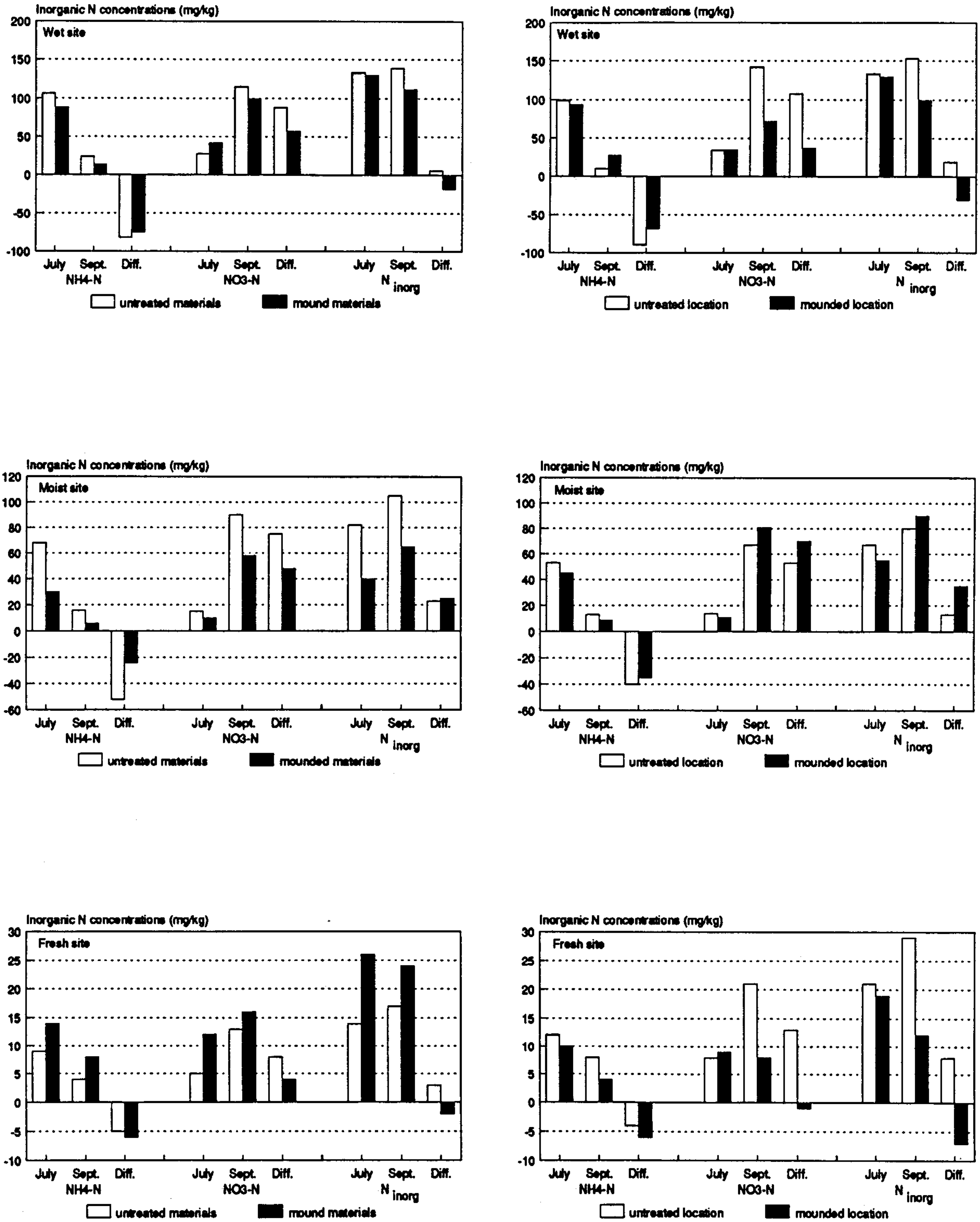


FIGURE 17. Average inorganic N concentrations at the beginning (July) and end (Sept.) of the incubation period, and differences (Diff.), by site, source of material, and location of incubation (Experiment "A").

TABLE 14. Probability levels for contrasts of soil inorganic N concentrations, Experiment "A": source of materials (untreated vs. mounded spots), location of incubation (untreated vs. mounded microsite), and untreated material and location vs. mounded material and location, by site.

Site / contrast	NH_4^+-N July	NH_4^+-N Sept.	NH_4^+-N Diff.	NO_3^--N July	NO_3^--N Sept.	NO_3^--N Diff.	N-inorg July	N-inorg Sept.	N-inorg Diff.
	Pr > F			Pr > F			Pr > F		
Wet site									
Source of material	0.4862	0.2732	0.7792	0.2499	0.5340	0.1804	0.9189	0.3662	0.4133
Location of incubation	0.8420	0.1104	0.3754	0.9518	0.0163	0.0055	0.8943	0.0881	0.1059
Untreated vs mounded	0.5266	0.6997	0.4099	0.3879	0.0322	0.0049	0.8682	0.0700	0.0898
Moist site									
Source of material	0.0088	0.0001	0.0349	0.1431	0.0123	0.0224	0.0156	0.0024	0.8915
Location of incubation	0.5257	0.0163	0.6998	0.2683	0.2393	0.1110	0.4566	0.3806	0.1437
Untreated vs. mounded	0.0206	0.0001	0.0746	0.0756	0.2750	0.5608	0.0261	0.0738	0.2532
Fresh site									
Source of material	0.0651	0.1198	0.6050	0.0112	0.3603	0.4313	0.0078	0.1504	0.3720
Location of incubation	0.5217	0.0675	0.5525	0.8025	0.0058	0.0062	0.7884	0.0027	0.0165
Untreated vs. mounded	0.3627	0.8249	0.4342	0.0422	0.1335	0.0128	0.0680	0.1692	0.0217

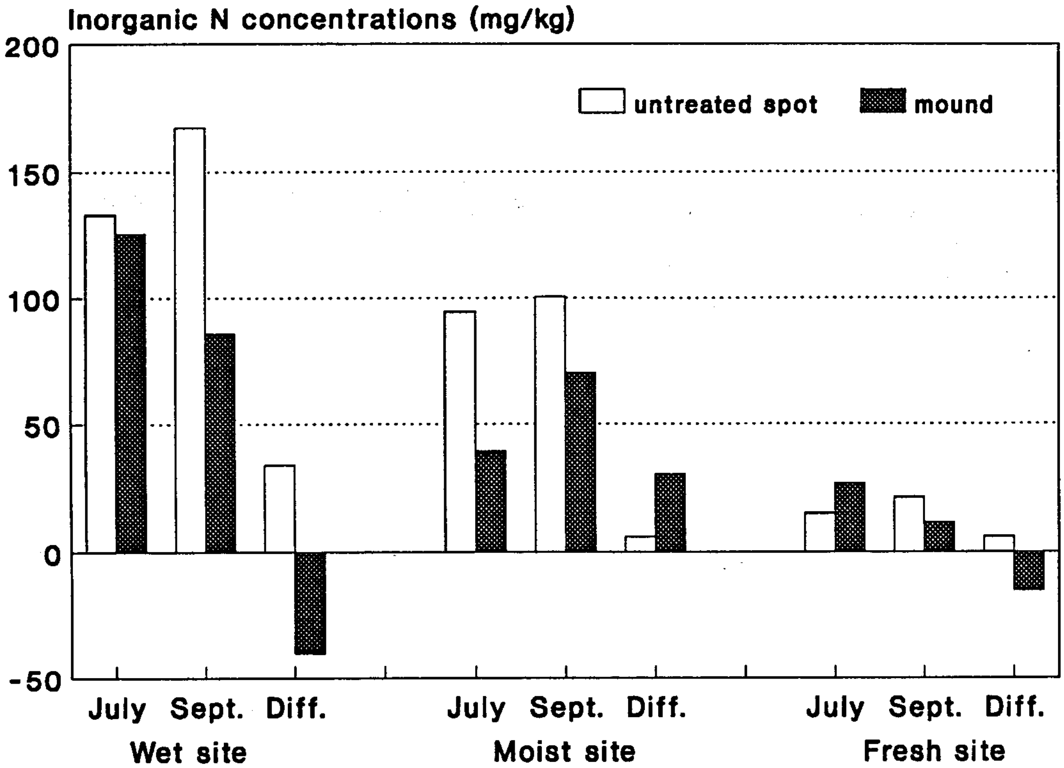


FIGURE 18. Inorganic N concentrations in untreated spots and mounds (materials incubated in place) at the beginning (July) and end (Sept.) of incubations and differences (Diff.), in wet, moist, and fresh sites.

mounds). Increases in NO_3^- and N_{inorg} after incubations were, however, greater in mounded locations, though statistically the effect was very weak effect ($p = 0.1110$ and 0.1437 respectively). T-tests showed post-incubation concentrations of N_{inorg} to be significantly greater than pre-incubation concentrations in mounded but not untreated locations. Contrasts of untreated vs. mounded spots were not statistically significant.

3.3.1.3 Fresh site

Results in the fresh site were the reverse of those in the moist site. Here, the source of material also had a highly significant effect on N_{inorg} levels at the beginning of incubations ($p = 0.0078$), however in this case mounded materials had higher concentrations of both NO_3^- and NH_4^+ than untreated materials. Location of incubation had significant effects on differences in NO_3^- and N_{inorg} following incubations ($p = 0.0128$ and 0.0165 respectively). As in the wet site, samples incubated in mounded spots showed almost no increase or net decreases in N_{inorg} following incubations, while those in untreated locations showed net increases. Contrasts of untreated vs. mounded spots showed significantly greater differences (increases in this case) in NO_3^- and N_{inorg} following incubations ($p = 0.0128$ and 0.0217 respectively) in untreated soils than in mounded soils. It should be noted however that while pre- and post-incubation levels of NO_3^- were significantly different according to the results of T-tests, differences in N_{inorg} were not significant in fresh and also wet sites (Table 13).

3.3.2 Experiment "B"

The chemical properties of the mineral soil material used in Experiment "B" differed from those of the combined forest floor and mineral soil samples examined in Experiment "A". Although total N, total C, and pH were relatively high and the C:N ratio was relatively low, the ratio of Min. N to total N was lower than for any of the Experiment "A" samples.

Following incubations there were increases in concentrations of NO_3^- and slight decreases in NH_4^+ in all cases (Table 15). Contrasts showed significant differences among some microsite treatments following incubations (Table 16).

TABLE 15. Mean soil concentrations of inorganic N in a standard soil material before incubation, after incubation by microsite, degree hour sums, and soil moisture content, for Experiment "B".

Microsite Treatment	Site	NH_4^+ ---------	NO_3^- mg/kg N	N_{inorg} ------	N_{inorg} Diff. mg/kg N	Degree hours > 5°C	H_2O (%)
Before incubation							
std material (July)	--	3.2	3.6	6.8	--	--	35
After incubations							
inv. mound (16)	moist	1.8 a[1]	29.9 a[1]	31.7 a	24.9 a	18318	64
inv. mound (8)	fresh	2.2 a	29.3 ab	31.5 a	24.7 a	15443	64
inv. spot	fresh	2.1 a	26.7 abc	28.8 ab	22.0 ab	14556	65
scalped spot	fresh	1.5 a	26.0 bc	27.5 b	20.7 b	12628	67
scalped spot	moist	1.5 a	24.6 c	26.1 b	19.3 b	11331	76
untreated spot	moist	2.0 a	23.9 c	25.9 b	19.1 b	10801	74

[1]Treatments labelled with the same letters are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$).

TABLE 16. Contrasts of changes in N concentrations following Experiment "B" incubations.

Contrast	NH_4^+-N	NO_3^--N	N_{inorg}
	---------	Pr > F	---------
untreated vs. scalped spots	0.0168	0.1861	0.4174
scalped vs. inverted spots	0.0108	0.1981	0.0849
untreated vs. inverted spots	0.8680	0.0288	0.0324
inverted spot vs. inverted mound	0.6663	0.0129	0.0166
scalped spots in moist vs. fresh sites	0.8031	0.2868	0.2773

Mean increases in NO_3^- and N_{inorg} concentrations in samples incubated in inverted mounds were greater than in any other treatment. Mean increases in N_{inorg} were greater in inverted mounds than in untreated spots, but differences between untreated and scalped spots and scalped and inverted spots were not statistically significant ($p < 0.05$).

Concentrations of NO_3^- and N_{inorg} following incubations increased with increasing soil temperature, expressed as degree hour sums (5°C base) calculated for each of the microsites during the incubation period (Figure 19). Soil temperature accounted for 49% of the variability in N-Min levels following incubations.

The soil moisture content of samples was uniform across all treatments at the beginning of incubations, however by September additional moisture had seeped into the bags, particularly in untreated and scalped spots in the moist site, increasing moisture contents by 10-12% relative to other treatments (Table 15). Samples from all treatments were moderately moist to very moist, though none to the point of saturation. Significant negative correlations were found between degree hour sums, NO_3, and N_{inorg} and soil moisture content at the end of the incubation period.

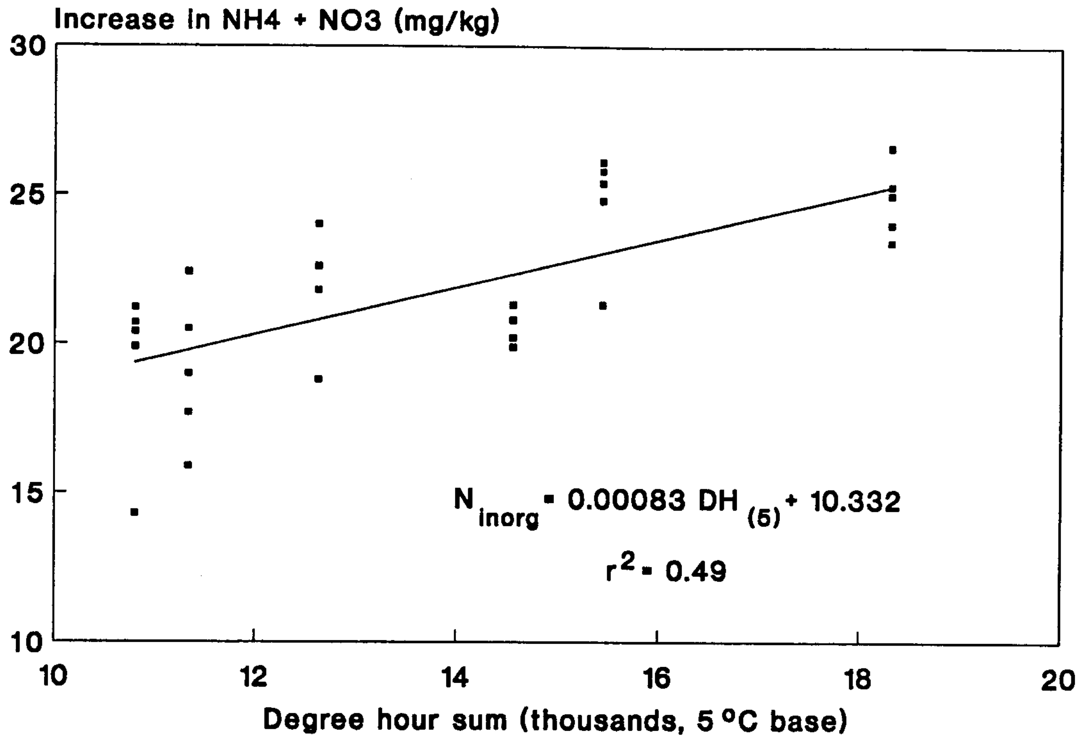


FIGURE 19. Relationship between degree hour sums calculated for each microsite and increases in inorganic N during incubations.

3.4 Discussion

3.4.1 Experiment "A"

This experiment addressed three separate issues related to N availability in the seedling rooting zone following mechanical treatments:

1. effects of inverted mounding treatments on soil chemical properties in the seedling rooting zone related to N content and availability;
2. effects of substrate quality on rates of N mineralization; and
3. effects of differing microsite thermal regimes on rates of N mineralization.

The interpretation of experimental results was complicated by apparent interactions among these factors and interactions between these factors and site characteristics, particularly forest floor depth.

3.4.1.1 Effects of inverted mounding treatments on N and C content

The effects of mounding on total N and C concentrations varied among sites, and depended primarily on forest floor depth. This was anticipated because N content is closely related to organic matter content. In the wet site, mound capping materials are very high in organic matter because forest floor layers are 20-30 cm in depth, therefore differences between cores from mounds and untreated spots were expected to be slight. In the moist site, cores from the untreated spot consisted predominantly of forest floor materials, because the forest floor is 12 to 15 cm in depth, whereas cores from mounds were more than 50% mineral soil by volume. In the fresh site, however, with its 4 to 6-cm forest floor layer, the proportions of organic matter and mineral soil in cores from untreated and mounded spots were more similar. Because these inverted mounds had 8 cm of mineral soil capping, the proportion of organic matter in samples from mounds was likely to be somewhat greater than that from untreated spots due to the doubled layer of forest floor materials at the base of the mound. Based only on total nutrient concentrations in the immediate rooting zone, the relative advantage of mounding from a nutritional point of view could potentially be greater in the fresh site than in the wetter sites.

3.4.1.2 Differences among sites in soil chemical properties

Moist site soils, particularly in mounds, had the highest pH levels and lowest C:N ratios. These are features that would be expected to favor microbial activity and net N mineralization. Although wet site soils had a very high total N content, C:N ratios in these materials were significantly greater than in moist site soils. Fresh site soils had a low total N content relative to wet and moist site soils, high C:N ratios, and low soil pH. All are features that would be associated with low rates of microbial activity and N mineralization. The observation of nitrification in all but fresh site mounds can likewise be understood in light of these unfavorable chemical properties and also low soil moisture levels (Table 13).

3.4.1.3 Effects of differing soil thermal regimes on N mineralization

Study results suggest a strong interaction between substrate quality and response to differing thermal regimes. Significant ($p < 0.05$) net N mineralization occurred only in the moist site among materials from mounds and among samples incubated in mounds. In wet and fresh sites, differences between pre- and post-incubation N_{inorg} were not statistically significant, but there was a consistent trend of net N immobilization in samples incubated in mounds.

Warmer temperatures would be expected to encourage a higher level of microbial activity in mounds relative to untreated locations. This resulted in greater net N-mineralization only in the moist site, likely due to the quality of the substrate (particularly the lower C:N ratio). In wet and fresh sites, where C:N ratios were higher, increased microbial activity resulted in net N immobilization rather than mineralization.

From a management perspective, it should be noted that even though these results suggest net immobilization of N in mounded wet site materials, at least during the first year after treatment, concentrations of inorganic N are sufficiently high that this should not have a negative effect on conifer growth. Similarly, in the moist site, even though measured rates of mineralization were greater in mounds, the concentration of inorganic N within the rooting zone of untreated soils was greater than that in mounds at the beginning and end of incubations. In the fresh site, although mounding increased total N concentrations in the rooting zone, it appeared to result in net N immobilization, such that inorganic N concentrations were significantly lower in mounded spots relative to untreated spots at the end of incubations.

It is possible that the trend of N immobilization in mounded soils with high C:N ratios may not persist. As the C content of materials declines over time from respiration, C:N ratios decline, potentially making greater rates of mineralization possible. Observations of Mälkönen (1986) and Rosén and Lundmark-Thelin (1986) cited by Örlander *et al.* (1990) suggest that rates of mineralization of N and other nutrients tend not increase until one or more years after mounding treatments, but then persist for at least three years.

3.4.2 Experiment "B"

The use of a standard soil material in this part of the study removed a large amount of variation associated with the highly variable substrates sampled in Experiment "A", isolating the soil temperature factor sufficiently to make it detectable. The effect of increasing N mineralization with increasing temperature has been observed under laboratory conditions (Salonius 1983; Theodorou and Bowen 1983; Foster 1989), but less often in field studies (eg. Powers 1990).

Powers (1990) compared rates of N mineralization in soils along an altitudinal gradient. When he expressed N mineralization as a proportion of total soil N to control differences in substate properties, he found a strong relationship of increasing N mineralization with increasing mean annual soil temperature.

Inorganic N concentrations were extremely low in the standard material at the beginning of incubations, but by the end had increased by two to three-fold, a greater proportional increase than was observed in moist site mound materials. Relative to those materials, the standard had very low mineralizable and total N concentrations, but had a similarly high pH and low C:N ratio. A very interesting extension of this experiment would be to include more than one standard material, in order to further investigate the nature of interactions between thermal environment and substrate quality.

The negative correlation of soil moisture content with increases in NO_3^- and N_{inorg} following incubations can be explained, at least in part, as an artifact of the negative correlation between soil moisture and soil temperature discussed in section 2.4. The range of moisture contents observed among treatments was relatively narrow and did not extend to levels low enough for ammonification to have been constrained by insufficient moisture. Of the ten samples incubated in moist site untreated and scalped spots, two may have been sufficiently moist to have been at least temporarily anoxic. This could have resulted in N losses through denitrification, or may simply have slowed ammonification.

4 EFFECTS OF MICROSITE ALTERATION ON SEEDLING ESTABLISHMENT

4.1 Introduction

Site preparation treatments are effective in optimizing rates of seedling survival and growth only to the extent that growth-limiting factors are alleviated at the microsite level. In subalpine, boreal and sub-boreal forests, low soil temperatures have frequently been cited as a particularly important growth-limiting factor (eg., McMinn 1982; Goldstein *et al.* 1985; Coates 1987; Brand and Janas 1988; Bassman 1989). However, frost, excess soil moisture, and competing vegetation are likely to be factors of equal or greater importance on some sites (Coates 1987; Grossnickle 1987; Stathers 1989).

Treatments that create raised microsites, such as mounding, were found in this study and several others (eg. Draper *et al.* 1985; Örlander 1986; Bassman 1989) to be most effective in terms of improving soil temperatures. Even though increased soil temperatures tend to be accompanied by decreased moisture levels in mounded spots, superior rates of seedling survival and growth are generally observed (eg. McMinn 1982; Draper *et al.* 1985; Bassman 1989; von der Gönna 1989; Örlander *et al.* 1990), except on very dry sites with coarse-textured soils (Örlander 1986). In addition to increasing growing season soil temperatures, mounding is also a highly effective means of improving soil drainage and aeration at the microsite level, and in some cases, particularly in large mounds, appears to reduce the exposure of seedlings to frost and competition for light from non-crop vegetation (Stathers 1989; Örlander et al. 1990).

McMinn (1982) demonstrated the importance of soil and site characteristics to the response of white spruce seedlings to bulldozer scalping and patch scalping treatments in a series of trials in the SBS zone. The degree of vegetation competition, soil drainage, and soil texture were all shown to be important factors. Blade scarification, and to a lesser extent patch scarification tended to increase seedling survival and early growth most on sites with a high potential for competing vegetation, provided soils were at least moderately well-drained and medium to coarse in texture. Scalped patches reduced survival and growth significantly relative to no treatment on a wet site, likely due to flooding during the spring. Bassman (1989) reported that patch scarification increased soil temperatures slightly at the 5-cm depth relative to controls on a moist, high elevation site in interior British Columbia, but there was little difference at greater soil depths. In that study, seedling growth in scarified patches was slightly better than in untreated spots, but differences were not statistically significant.

The objective of this component of the study was to compare the effectiveness of four types of microsite treatment: scalped spots, inverted spots, inverted mounds, and mineral mounds relative to no treatment in encouraging the survival and successful establishment of interior spruce in three site types within the climatic context of the SBSmc subzone.

4.2 Methods

Site and soil characteristics are described in Table 1 and depicted in Figure 2. Microsite treatments are depicted in Figure 3. The combinations of site and microsite treatment included in the experiment are shown in Figure 4. Microsite treatments were randomly assigned to five spots in each of the 5 study plots established in wet, moist and fresh sites. In total there were 25 replications of each of 16 combinations of microsite treatment and site. A total of 400 seedlings were planted, one per spot.

Seedlings used in the study were one-year-old interior spruce, raised by a commercial nursery in Styroblock containers with cavities 3 cm in diameter and 13 cm in depth. Prior to planting in late May 1987, seedlings were sorted for size and quality. Those that appeared to be in poor condition (eg. those showing mechanical damage to the root or shoot, and those with very small or discoloured needles), and those that were unusually large or small were discarded. Measurements of height and root collar diameter were recorded at planting in May, 1987 and repeated in September, 1987, 1988, and 1989 along with seedling condition and the current year's leader growth. The condition of live seedlings was assessed as good, fair, or poor. Seedlings judged to be in good condition had no visible defects likely to inhibit growth, while those judged to be in fair condition showed some evidence of damage (often from frost) or reduced vigour (eg., slight chlorosis or small needles) to the extent that seedling growth appeared to be impaired but survival was not threatened. Those judged to be in poor condition were severely damaged (usually by frost or flooding), to the extent that the continued survival of the seedling was in doubt. Visible damage and defects were recorded in general terms (eg., 'dead terminal bud' or 'chlorotic') and where possible the probable cause was identified (eg., frost or flooding).

Data were analyzed as a split plot design with site as the mainplot factor applied to plots. Two sets of statistical analyses were done, one to examine effects of site and those treatments common to all sites (Table 17) and another to examine effects of all treatments within each site separately (Table 18).

TABLE 17. ANOVA for effects of sites and treatments on seedlings.

Source	Df	Error
Mainplot:		
Site	2	Plots(Site)
Plots	12	Trees(Plots Site Treatment)
Split plots:		
Treatment	3	Plot(Site) * Treatment
Site * Treatment	6	Plot(Site) * Treatment
Plot(Site) * Treatment	36	Trees(Plot Site Treatment)
Subsampling:		
Trees(Plot Site Treatment)	240	--
Total	299	--

TABLE 18. ANOVA for effects of treatments on seedlings, within sites.

Source	Fresh Df	Moist Df	Wet Df
Plot	4	4	4
Treatment	4	5	4
Plot * Treatment	16	20	16
Trees	100	120	100
Total	124	149	124

4.3 Results

4.3.1 Height and diameter growth

More than 60% of the height growth during the three-year period occurred in the first growing season (Fig. 20). There were no statistically significant differences among treatments at the end of the first year (1987), but height growth in mounds tended to be somewhat lower than that in scalped and untreated spots (Table 20). During the second season (1988), height increments decreased drastically, averaging -1 to 3 cm (negative values due to severe frost damage to terminal buds), but were significantly greater in inverted mounds than in any other treatments. Seedling height increment in 1989 and total height growth from planting to fall of 1989 were significantly greater in inverted mounds than in other treatments in all sites (Tables 19 & 20). On wet and moist sites, both height and diameter growth were lowest in scalped spots and greatest in inverted mounds.

Site had significant ($p < 0.05$) effects on height and diameter growth (Table 21). Frost damage affected four out of five study plots in the fresh site, which resulted in reduced height but not diameter growth compared to the other sites. Height growth was greatest in the moist site and poorest in the wet site during 1988 and 1989. In the one fresh site plot that was not as heavily impacted by frost, average height growth across all treatments was equal to the average for all moist site plots. Diameter growth was the same (1987, 1988) or greater (1989) in the fresh site relative to the moist site and least in the wet site.

4.3.2 Seedling survival and condition

Irrespective of site, seedlings planted in inverted mounds were those most frequently found to be in good condition after the third growing season, while those planted in scalped spots were least frequently in good condition (Table 19), although differences among treatments were not statistically significant.

Survival rates were in all cases close to 100%, except in a particularly low-lying study plot in which seedlings were repeatedly damaged by severe frosts, and in scalped spots on wet plots, which were flooded for several weeks each spring.

4.3.3 Effects of frost on seedlings

Frost events during late June and early July of 1988 (second growing season) (Fig. 6) resulted in damage to the current year's growth on many seedlings. In

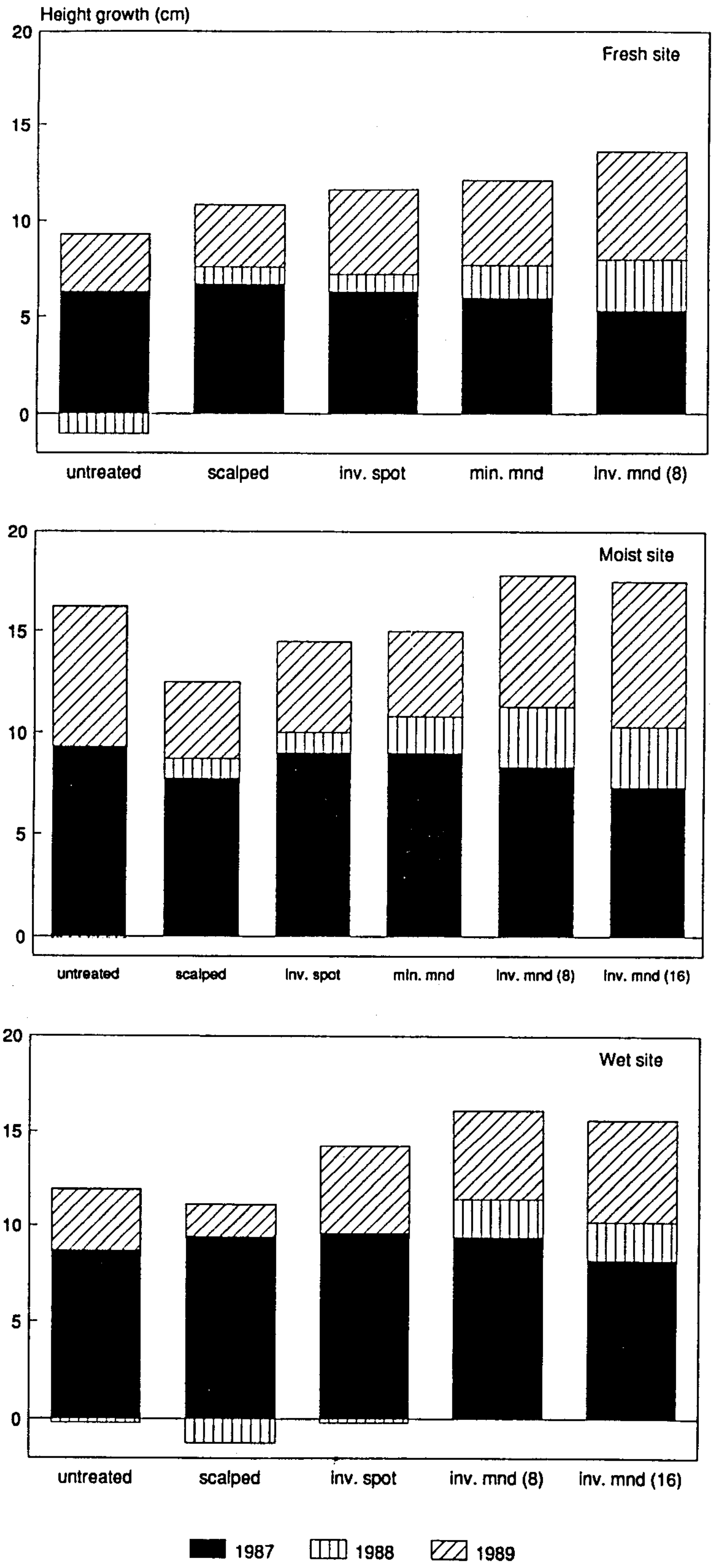


FIGURE 20. Seedling height growth during the first three growing seasons, by site and treatment.

TABLE 19. Response of interior spruce seedlings, by site and treatment.

	Untreated spot	Scalped spot	Inverted spot	Inverted mnd (8)	Mineral mnd
Fresh site					
Total height (cm)					
1989	32.5	33.6	34.6	36.4	35.3
Height increment (cm)					
1987	6.3	6.7	6.3	5.3	6.0
1988	-0.7 c*	0.9 bc	0.9 bc	2.7 a	1.7 ab
1989	3.0	3.2	4.4	5.6	4.4
1987-89	8.7 b	10.7 ab	11.7 ab	13.5 a	11.2 ab
Diameter (mm)					
1989	7.8	8.1	8.6	8.2	8.6
Diameter increment (mm)					
1987	1.5	1.4	1.4	1.3	1.4
1988	0.9	1.1	1.5	1.4	1.4
1989	2.4	2.4	2.5	2.5	2.6
1987-89	4.9	5.0	5.4	5.3	5.4
Survival (%)					
1989	100	100	100	100	100
In good condition (%)					
1989	63	60	73	92	81

* Within years, means followed by the same letter are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$). Where no letters follow treatment means, there were no significant differences among treatments.

TABLE 19. (cont.) Response of interior spruce seedlings by site and treatment.

	Untreated	Scalped spot	Inverted spot	Inverted mnd (8)	Inverted mnd (16)	Mineral mnd
Moist site						
Total height (cm)						
1989	41.9	34.6	36.5	38.9	40.9	38.2
Height increment (cm)						
1987	9.4	7.7	9.0	8.3	7.3	9.0
1988	-0.1 b	1.0 ab	1.0 ab	3.0 a	3.0 a	1.8 ab
1989	6.9 ab	3.8 c	4.5 abc	6.5 abc	7.2 a	4.2 bc
1987-89	16.4 ab	12.6 b	14.5 ab	17.8 a	17.6 a	15.0 ab
Diameter (mm)						
1989	8.0 ab	7.3 b	7.7 ab	8.3 ab	8.7 a	7.6 b
Diameter increment (mm)						
1987	1.8	1.9	1.8	1.8	1.6	1.9
1988	1.3	1.0	1.2	1.3	1.4	1.0
1989	1.8 ab	1.4 b	1.8 ab	2.3 ab	2.5 a	1.7 ab
1987-89	5.0 ab	4.3 b	4.8 ab	5.3 ab	5.6 ab	4.6 ab
Survival (%)						
1989	96	96	100	100	100	100
In good condition (%)						
1989	72	48	76	88	84	72

* Within years, means followed by the same letter are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$). Where no letters follow treatment means, there were no significant differences among treatments.

TABLE 19. (cont.) Response of interior spruce seedlings, by site and treatment.

	Untreated	Scalped spot	Inverted spot	Inverted mnd (8)	Inverted mnd (16)
Wet site					
Total height (cm)					
1989	36.4 b	34.6 b	39.3 a	40.5 a	40.6 a
Height increment (cm)					
1987	8.7	9.4	9.6	9.4	8.2
1988	-0.2 b	-1.2 b	-0.2 b	2.0 a	2.0 a
1989	3.2 bc	1.7 c	4.6 ab	4.7 ab	5.4 a
1987-89	11.7 bc	9.8 c	13.9 ab	16.2 a	15.6 a
Diameter (mm)					
1989	6.5 bc	6.1 c	7.2 b	8.1 a	8.3 a
Diameter increment (mm)					
1987	2.0 a	1.5 b	1.8 ab	1.9 a	1.9 a
1988	0.5 c	1.0 b	0.6 bc	0.9 b	1.5 a
1989	1.1 c	0.5 d	1.6 bc	2.2 a	1.8 ab
1987-89	3.6 bc	3.1 c	4.0 b	5.0 a	5.2 a
Survival (%)					
1989	81	64	84	96	96
In good condition (%)					
1989	54	16	60	73	80

* Within years, means followed by the same letter are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$). Where no letters follow treatment means, there were no significant differences among treatments.

TABLE 20. Contrasts of treatments for seedling response variables, by site.

Site	Fresh	Moist	Wet
	----------------	Pr > F	----------------
Height increment, 1989			
Untreated vs. treated	0.1413	0.0303	0.2085
Inverted mounds vs. others	0.0099	0.0006	0.0015
Scalped vs. untreated	0.8390	0.0017	0.0894
8 vs. 16 cm inverted mound	--	0.4725	0.3674
Diameter increment, 1989			
Untreated vs. treated	0.6125	0.6325	0.0482
Inverted mounds vs. others	0.8350	0.0002	0.0001
Scalped vs. untreated	0.9061	0.0261	0.0393
8 vs. 16 cm inverted mound	--	0.3995	0.3995

TABLE 21. Effect of site on seedling response: average of all treatments.

Site	Fresh	Moist	Wet
Total height (cm)			
1989	34.3 b	38.0 a	37.7 a
Height increment (cm)			
1987	6.1 b	8.6 a	9.3 a
1988	1.0 a	1.2 a	0.1 b
1989	4.1 b	5.5 a	3.5 b
Diameter (mm)			
1989	8.1 a	7.8 a	7.0 b
Diameter increment (mm)			
1987	1.8 a	1.8 a	1.4 b
1988	1.2 a	1.2 a	0.8 b
1989	2.5 a	1.9 b	1.3 c

* Within years, means followed by the same letter are not significantly different (Tukey's Studentized Range (HSD) test, $p < 0.05$).

many cases it caused damage to some or all of the new foliage on lateral stems. In extreme cases the terminal bud was destroyed. The total number of seedlings showing some degree of observable frost damage varied among plots (those in lower slope positions being most affected), but did not vary significantly among treatments (data not shown). However, in those plots which were most severely affected by frost, trees planted in inverted and mineral mounds tended to be less damaged than those in other treatments. For example, among the four fresh site plots that were hardest hit by frost, the occurrence of terminal bud damage from frost during 1988 was twice as frequent among seedlings planted in scalped, inverted, and untreated spots than it was in inverted and mineral mounds.

4.3.4 Response of natural vegetation

The response of natural vegetation to microsite treatments was not examined in any detail. On fresh and wet sites non-crop species were not sufficiently prolific to pose any threat to planted seedlings. A vigorous growth of low shrubs and herbs did, however, develop on one of the five moist site study plots. In that plot, seedling height growth was below average in all treatments, but was greatest in inverted mounds.

4.4 Discussion

Although there were no statistically significant differences among the microsite treatments in seedling height and diameter growth at the end of the first growing season, growth was on average slightly less in inverted mounds than in controls and other treatments. By the third growing season however, seedling height and diameter growth were significantly greater in inverted mounds than in other treatments. This result is consistent with the findings of other studies in sub-boreal and subalpine forests in British Columbia (McMinn 1985; Draper *et al.* 1985; Bassman 1989) and under similar climatic conditions in Scandinavia (Örlander *et al.* 1990). In the present study, and in a study reported by Bassman (1989), seedlings in mounds appeared to be at a slight disadvantage relative to those in other treatments at the end of the first growing season, likely because of lower soil moisture levels. It is likely that until sufficient roots are established, seedlings in mounds will experience some degree of moisture stress, particularly later in the season when soil moisture levels tend to be at a minimum.

The fact that seedlings in mounds have been observed ultimately to outperform those in other treatments in spite of lower soil moisture levels has been attributed to enhanced root growth associated with increased soil temperatures (Örlander 1986; Bassman 1989; Binder *et al.* 1989; von der Gönna 1989). In moist to wet sites in a more interior subzone of the Sub-Boreal Spruce Zone, von der Gönna (1989) reported increases in numbers of new root tips and total root mass of close to 100% in interior spruce seedlings planted in inverted mounds relative to those in scarified patches and untreated spots.

Aside from limiting rates of root development, low soil temperatures have also been shown to inhibit the absorption of water in both Engelmann spruce (Kaufmann 1975) and white spruce (Grossnickle and Blake 1985). Kaufmann (1975) attributed this to the combined effects of increased viscosity of water in the soil and roots and increased root resistance at low soil temperatures. Higher soil temperatures in mounds may therefore be an important compensating factor for the tendency to lower soil moisture levels in mounded spots. For example, Bassman (1989) observed no differences in xylem pressure potential among seedlings planted in untreated, scarified, and mounded spots at a time when soil water potentials were significantly lower in mounds, but soil temperatures were significantly higher.

In addition to low soil temperatures, early summer frosts appeared to be an important growth-limiting factor in this study area. Site characteristics match many of the criteria described by Stathers (1989) for frost prone sites, ie., a moderately large clearcut area on flat to gently sloping terrain with a northerly aspect. The study plot that suffered the greatest frost damage was located at the foot of the clearcut, within 100 m from the edge. The observation of extremely slow growth in all sites, irrespective of treatment, during the second growing season may be attributed to a large extent to frequent and severe frosts during June and July of that year. Between June 1 and June 20, air temperatures at 20 cm above the ground surface fell below -4°C on four separate occasions. In addition to causing observable damage to the shoot, low air temperatures can also retard growth through the inhibition of photosysnthesis, particularly early in the growing season. Delucia and Smith (1987) observed substantial reductions in photosynthesis in Engelmann spruce after exposure to night air temperatures of -4 to -5°C during mid-June. They found that later in July and August, decreased photosynthetic rates were better correlated with low soil temperature.

In the present study the terminal buds of seedlings planted in mounded spots were less often damaged by frost than were those in untreated, scalped, and plowed spots, suggesting that the mounded spots afforded some degree of protection from frost damage on this site. According to Örlander *et al.* (1990) mounding may be expected to reduce frost damage both by increasing the elevation of the tree above the ground surface and by increasing outgoing radiation from the soil, particularly following warm, clear days when soils have absorbed a great deal of heat.

Flooding appeared to be another important growth limiting factor in the present study, but only in moist and wet sites. The spot scalping treatment greatly exacerbated the problem of excess soil moisture early in the season, as was also observed by McMinn (1982). In the present study, contrasts showed height and diameter growth to be significantly greater in untreated spots than in scalped spots during the third growing season in wet and moist sites, but differences between the two were not significant in the fresh site. Similarly, von der Gönna (1989) reported greater root growth in controls relative to scarified patches on two moist to wet sites, but superior growth in scarified patches on two better-drained sites. In a laboratory study, Grossnickle (1986) observed no root growth in white spruce seedlings exposed to flooded soils for 14 days at soil temperatures of 10 and 20°C. Levan and Riha (1986) found that flooding for longer than one day suppressed transpiration by up to 50% and killed all existing root tips of white spruce seedlings.

Of the treatments examined in this study, inverted mounds appeared to provide the most favorable environment for the survival and growth of young planted seedlings on fresh, moist, and wet sites. Seedlings planted in mounds had important advantages throughout the growing season: a warmer and better-drained rooting environment during May - early June when soils were particularly cold and wet, lessened exposure to damaging frost during the period of active shoot growth from mid-June to late July, and a better-developed root system, providing greater access to moisture and nutrients.

5 SUMMARY AND MANAGEMENT IMPLICATIONS

It is important to recognize that the results of this study reflect a specific set of environmental conditions, in particular the relatively moist, cool climate of the SBSmc subzone. The response of soil moisture and temperature to these mechanical treatments may differ in important ways under different climatic conditions, particularly in drier climates such as in the southern interior of B.C.. Also, the response of seedlings to these treatments are likely to be quite different in areas with drier and/or warmer climates as in the southern interior or in coastal areas, where the factors limiting to growth are in many cases quite different.

5.1 Effects of Treatments on Soil Climate

From May through August, the inverted mound treatment increased daytime soil temperatures in the seedling rooting zone substantially relative to no treatment. Mineral mound and spot inversion treatments also increased growing season soil temperatures, but to a lesser extent. Increasing the elevation and surface area of the mineral mound treatment (relative to the size of mound tested in this study) would likely result in warming comparable to that observed in the inverted mounds. Spot scalping resulted in slight temperature increases compared to the control in the fresh site but had little or no warming effect in the moist or wet site. Simply removing the forest floor would appear to have a warming effect where soils are relatively well drained. However, on sites where soil moisture levels are very high, particularly following snowmelt in the spring, increasing soil temperatures significantly requires improving soil drainage by creating a raised microsite.

During periods of low rainfall, inverted mounds became substantially drier than other treatments, but the duration and intensity of the drying trend varied among the three sites. While mounded soils (particularly inverted mounds) became extremely dry on occasion in the fresh site during late July to mid-August, they rarely dropped below -0.2 MPa in the wet site. However, even in the fresh site, seedling survival and growth rates did not appear to suffer significantly from moisture deficits beyond the first growing season. Increased soil temperatures appear to compensate for decreased moisture availability, likely both by encouraging rapid root growth, and by alleviating the increased root resistance to water uptake associated with low soil temperatures.

The problem of excess soil moisture early in the growing season in moist and wet sites was greatly exacerbated by the spot scalping treatment. Particularly in the wet site, flooding resulted in substantially reduced vigour, and in some cases seedling mortality. Similar effects can be observed even in the absence of mechanical patch scarification, on moist to wet sites with deep forest floor layers, where planters have been instructed to screef down to mineral soil. This process frequently yields planting spots that become small water-filled wells for several weeks early in the growing season, with similarly negative effects on seedling survival and growth. On these sites, shallower screefs or the selection of naturally raised microsites can greatly increase seedling survival and growth, provided there is an appropriate mineral or well-decomposed organic substrate.

Seedlings in all sites and treatments were affected by frost during the period of rapid shoot growth in late June to mid-July. Inverted and mineral mound treatments did, however, appear to confer some degree of protection, to the extent that damage due to frost appeared to be less severe in these treatments. The mounds examined in this study were relatively small in size. Larger excavator-built mounds that provide greater elevation above the cold ground surface (up to approximately 40 cm) and a larger volume of soil to store greater amounts of heat would likely provide significantly greater relief from frost damage. On sites with severe frost potential, however, other measures may be required, such as selecting a more frost-tolerant conifer species, designing cutblock boundaries to permit the drainage of cold air, and using harvesting methods other than clearcutting to reduce longwave radiation heat losses (Stathers 1989).

5.2 Effects of Treatments on Nitrogen Mineralization

Amounts of N mineralized from a standard soil material during a 77-day incubation period in the field under a range of soil thermal regimes were positively correlated with degree hour sums calculated for each microsite. This would suggest that increased soil temperatures following mechanical treatments such as mounding may result in increased N availability by increasing the rate of N mineralization, at least over the short term. Although other factors, such as soil moisture and wetting and drying cycles, which are also affected by mechanical treatments and can have an impact on N mineralization were not examined in this experiment, studies in Scandinavia have demonstrated increased rates of N mineralization within a few years of mounding and mixing treatments (Örlander *et al.* 1990).

The inverted mound treatment affected the thermal regime and soil substrate composition in the rooting zone, both of which affected rates of N mineralization during incubations in the field. Effects of mounding on substrate quality varied among the sites depending primarily on forest floor depth. In this experiment, rates of N mineralization appeared to be controlled by an interaction between soil temperature and substrate quality. In wet and fresh sites where the C:N ratio of the substrate was relatively high, net N immobilization occurred in mounded microsites, however in the moist site where the C:N ratio was lower, net N mineralization occurred in both mounded and untreated microsites, but at a greater rate in the mounded spots.

Even where net N immobilization occurs initially in materials with high C and low N contents, this is likely to be followed within a few years by a period of increased N mineralization as the C:N ratio of the materials declines with the respiration of C, as has been observed in other studies (Örlander *et al.* 1990). Given that during the first season after planting, containerized seedlings are generally supplied with fertilizer in the root plug, the delay of enhanced N availability for a year or more following planting may not be a disadvantage.

5.3 Effects of Treatments on Seedling Establishment

After three growing seasons, seedling height and diameter growth were greatest in inverted mounds irrespective of site. Mineral mound and inverted spot treatments improved growth relative to no treatment and spot scalping, but were not as effective as the inverted mounds. Spot scalping increased seedling growth relative to no treatment only on the fresh site, likely because this treatment increased the severity and persistence of saturated soil conditions in moist and wet sites early in the growing season.

By the second growing season, the potential disadvantage of decreased moisture availability in mounds appeared to be outweighed by the benefits of improved soil temperatures, decreased exposure to damage from frost, and on moist and wet sites, improved soil drainage and aeration. The development of an effective root system is likely the most crucial achievement for seedlings during the establishment phase, and the increased warmth and improved aeration provided by mounding appears to be very effective in encouraging root growth in the moist cool climate of the SBSmc subzone.

During the three years of the study, the degree of competition for light and other resources from natural vegetation in the study area was low on fresh and wet sites, and moderately severe on only two of the five moist site study plots. Although it is common in the SBSmc subzone for non-crop vegetation to be relatively sparse and non-competitive with planted seedlings on fresh and drier sites, the rapid development of herbs and shrubs on some moist and wet sites can in many cases pose a far more serious limitation to growth than was observed in this study. In such cases the probable response of competing vegetation to the various treatment options is an important consideration. Optimizing the vigour and rate of growth of the planted seedling by improving microenvironmental conditions will improve its ability to compete successfully with non-crop vegetation. This may at least partially explain the observation of improved survival and growth in large inverted mounds in trials of mechanical site preparation equipment on sites with high brush potential in the SBS and ICH Zones (L. Bedford, B.C. Ministry of Forests, Victoria, B.C., pers. comm., March 1991; A. Macadam, unpublished data, 1990, B.C. Ministry of Forests, Smithers, B.C.).

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