National Library of Canada
Bibliothèque nationale du Canada

Canadian Theses Service
Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, tests publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30.

NL-339 (r. 88/04)

Canada

THE UNIVERSITY OF ALBERTA

FACTORS AFFECTING WHITE SPRUCE (PICEA GLAUCA) SEED GERMINATION ON BURNED FOREST LITTER

BY

MARIE RENEE COYEA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN
PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF
MASTER OF SCIENCE

DEPARTMENT OF FOREST SCIENCE

EDMONTON, ALBERTA
FALL, 1988

ISBN 0-315-45541-1

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: Marie Renée Coyea

TITLE OF THESIS: Factors Affecting White Spruce (_Picea glauca_) Seed Germination on Burned Forest Litter.

DEGREE: MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED: 1988

Permission is hereby granted to THE UNIVERSITY OF ALBERTA LIBRARY to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

(SIGNED) Marie R. Coyea

PERMANENT ADDRESS:

236 Herchimer Avenue
Belleville, Ontario
K8N 4G8

Date: August 5 1988.

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled FACTORS AFFECTING WHITE SPRUCE (*PICEA GLAUCA*) SEED GERMINATION ON BURNED FOREST LITTER submitted by MARIE RENEE COYEA in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

Victor Lieffers
Dr. V.J. Lieffers
Co-Supervisor

Dr. P.M. Woodard
Co-Supervisor

Walter Moser
Dr. W. Moser

Dr. M.G. Weber

Date: AUG - 5 1988

DEDICATION

To My Parents, For A Lifetime of Experience.

ABSTRACT

Two environmental factors common after slash burning were studied because of their potential impact on white spruce (Picea glauca (Moench) Voss) seed germination. These factors were: seedbed temperatures and the physical and chemical effects of burned residues from boreal mixedwood forest litter. In a field study on an upland burned site in north-central Alberta, soil and air temperatures were documented on shaded and exposed sites of low and high albedos, and on exposed scarified sites of medium albedo. A sensor was also established in a standard weather shelter (Stevenson screen). Air temperatures as high as 65°C were recorded on exposed sites, and as high as 43°C on shaded sites. Weekly maximum temperatures were consistently ranked from high to low as follows: high albedo open; low albedo, open; medium albedo, open; low albedo, shaded; high albedo, shaded; and Stevenson screen. There were few statistical differences among average, maximum and minimum temperatures recorded on microsites of different albedo types.

A factorial experiment under controlled laboratory conditions tested the germination response of two white spruce seed sources to four seedbed conditions (distilled water, fresh ash, leached ash and leachate from ash), subjected to five temperature regimes where temperatures were elevated for two hours by 10°C, 15°C, 20°C, 25°C, and 28°C, from a constant base temperature of 20°C. Percent

germination decreased as temperature increased. Germination was consistently lowest on fresh ash. Distilled water (control substrate) yielded highest germination percentages for all temperature treatments. The number of days required for fifty percent germination increased as temperature increased. Chemical analyses of the substrates used in this experiment showed that poor germination on ash substrates was not due only to salinity, although high pH may have been partially responsible. The markedly low germination on the leached ash suggested that there may have been some other chemical inhibitors, possibly organic compounds.

ACKNOWLEDGEMENTS

I sincerely thank my co-supervisors Dr. Vic Lieffers, and Dr. Paul Woodard, who as my teachers made the pursuit of this degree a positive, educational experience. I extend a special thanks to the other members of my supervisory committee, Dr. Walter Moser, and Dr. Mike Weber for sharing their scientific expertise and time.

Several individuals who assisted in the completion of this project, are gratefully acknowledged: D. Stelter for field and laboratory assistance; Dr. T. Taerum for statistical advice; A. Ferguson for field and computer assistance; M. Belanger of Campbell Scientific for technical advice about CR21's and 21X's; R. James for advice on the university main frame computer systems; M. Bokalo for assistance with Energraphics; R. Kroon and H. Welling for their assistance with the phytotron and greenhouses; The Alberta Forest Service, especially B. Bereska and S. Turner, for their assistance in establishing and maintaining the field study site at Calling Lake; The Canadian Forestry Service at the Northern Forestry Centre in Edmonton, especially G. Chroziewicz for scientific advice, the Fire Management Section for the use of their burning table, R. Hurdle for assistance in creating thermistors, and Dr. Y. Kalra for the analysis of leachates used in this study; the Department of Plant Science of the University of Alberta for the use of

photography equipment and microscopes; The Department of Soil Science of the University of Alberta, especially J. Konwicki, for chemical analysis of germination substrates; Chevron Oil Company for access to the Calling Lake field site; and finally the Pine Ridge Nursery for donating the white spruce seed for the germination experiments.

Special thanks are due to the Canadian Forestry Service-NSERC Block Grant, and an NSERC Operating Grant for financial support.

I would also like to express a heartfelt thanks to my fellow graduate students for all their words of advice and their encouraging spirit.

Special thanks are due to the Canadian Forestry Service-NSERC Block Grant, and an NSERC Operating Grant for financial support.

I would also like to express a heartfelt thanks to my fellow graduate students for all their words of advice and their encouraging spirit.

LIST OF TABLES

Table 3.6. Mean R_{50} values for each temperature regime at each substrate, for seedlots A and B combined, by Scheffe's multiple comparisons [10].

Substrate	Temperature Regime (°C) 30	35	40	45
Fresh Ash	12.9a	13.5a	11.0a	14.3a*
Leached Ash	12.0a	12.8a	15.6a	16.1ab
Leachate	13.0a	13.4a	13.9a	18.7ab
D. H2O	13.1a	12.1a	14.8a	16.9b

[10] Comparisons were made on each column independently. Values followed by similiar letters were not significantly different at $p<0.05$.

*Note: only 4 seeds germinated in the fresh ash at 45°C.

Table 3.7. Chemical analysis of soluble components of ash extracts and total chemical analysis of leached and fresh ash (*)

	Analyses of Water Soluble Nutrients			Analysis of Total Digests	
	Experimental Treatments				
	Leached Ash (**)	Leachate (**)	Fresh Ash (**)	Leached Ash (***)	Fresh Ash (***)
N Total	5.38	4.14	6.13	1854	1672
NH4	1.43	1.06	2.58	-	-
NO3	0.29	1.32	1.70	-	-
P	-	-	-	6818	6216
K	52.96	358.98	194.62	4946	8455
Na	6.82	4.33	8.62	1227	827
Mg	25.27	2.05	12.77	7066	6764
Ca	16.95	16.75	19.92	149000	139000
S	8.42	121.06	152.05	-	-
Al	0.2269	0.2400	0.0872	-	-
Fe	0.0017(+)	0.0017(+)	0.0017(+)	11000	9019
Mn	0.0088	0.0005	0.0056	2101	2067
Zn	0.0026(+)	0.0026(+)	0.0028	-	-
C	-	-	-	68800	61700
Sp.Cond. (mS/cm at 25 C)	.25	.73	1.12	0.8	8.8
pH:	9.2	10.2	9.9	10.3	11.5

(*) All concentrations are in ppm.
(**) Concentrations of total dissolved ions in three ash solutions (leached ash, leachate, and fresh ash), experienced by seeds.
(***) Analysis of total digest of ashes (Leached Ash, Fresh Ash).
(+) Detection limit of instrument. Actual reading is between zero and detection limit.

Total elemental concentrations for each substrate were not consistently ranked in order of magnitude. The leachate had the highest amounts of K and S, since these elements are among the most soluble ions (Black 1965), and could be leached considerably in the 10 washings. The Al ion was also abundant in the leachate. The leached ash solution had the highest concentrations of Mg, and Mn, and had NH4 concentrations higher than the leachate. The fresh ash solution had the highest concentrations of Ca, S, Na, Zn, total-N, NH_4, and NO_3.

Analysis of the total constituents of the leached and fresh ash indicated that K was the main element removed in the leaching process (Table 3.7). The total concentrations of the other elements remained virtually the same. The specific conductance of the saturated paste extract, indicated that the dissolved ion concentration of the leached ash was lower than that of the fresh ash.

3.4. DISCUSSION

In general, this experiment established that seed germination was inhibited on ash seedbed media especially at high temperatures, even when the specific conductivity of the media was low. The concentrations of ash used in this experiment were probably lower than might be found on a piled and burned slash site.

Germination is normally dependent on temperature, and proceeds more rapidly at higher temperatures (Mayer and Poljakoff-Mayber 1982), but temperatures above 35°C were detrimental to seed germination on all seedbeds. The marked decrease in germination percent on all media from 35° C conditions to 40°C, agreed with work by Fraser (1971) who found that white spruce germination decreases at temperatures higher than 38°C.

It has been reported that germination failure on burned areas has been due to higher pH and higher concentration of the nutrient solution resulting from soluble ash (Sims 1968). Studies from other disciplines besides forestry, have shown that as the solute concentrations increase, seed imbibition decreases largely due to osmotic effects. Under saline conditions these toxic effects may be especially pronounced (Mayer and Poljakoff-Mayber 1982). However, in this experiment it should be noted that the specific conductance and the pH were lower in the leached ash solution than in the leachate medium. This did not support the osmotic and pH inhibition theories cited above, suggesting that it was not a simple salinity problem, even though pH may have been partially responsible.

The markedly low germination response on the leached ash suggests that the combination of chemical elements or some unidentified agent in the ash was responsible for the effects of substrate on germination. Germination response was lowest in the fresh ash medium; this solution had the highest amounts of Na, S, Ca, total N, NH_4 and NO_3. The highest germination occurred on the leachate medium, with the lowest amounts of Na, Ca, total N, NH_4, Mg, and Mn). The reason for relatively poor germination on the leached ash compared to the leachate might be explained by the relatively higher concentrations of total N, NH4, Na and Mg. The organic component of the fire residues remains unknown but there is evidence that organics released from fire residues do affect germination (Keeley and Pizzorno 1986). Organic components may not pass the filters and thus are retained in the washed ash. This may also explain the higher germination in the leachate medium. Overall, however, the results of this experiment contradicted reports for other tree species which reported that ashbeds and their chemical constituents had either no effect or a positive effect on tree seed germination (e.g. Hermann and Chilcote 1965, DeKeijzer and Hermann 1966, Sims 1968, Woodard 1983, and Woodard and Cummins 1987).

The results of this experiment have several management implications. First, high soil surface temperature environments are detrimental to white spruce germination. Therefore steps should be taken to reduce the probability of hot microsites. Second, if seeding follows burning, better germination results would be expected with fall burning and spring seeding, rather than spring burning followed immediately by seeding. The reason is that ash would be given time to leach or erode over the winter after fall burning. This may promote higher germination, provided that spring temperatures are not high. Third, based on only two provenances, we found that ash was equally detrimental; therefore postburn ash should be reduced.

3.5. LITERATURE CITED

Arnott, J.T. 1973. Germination and seedling establishment p. 55-66. In: Cayford, J.H. (ed.). 1973. Direct seeding symposium. Dept. Environ. Can. For. Serv. Pub. No. 1339. Ottawa.

Black, C.A. (ed.). 1965. Methods of soil analysis. Part 2. Chemical and microbiological properties. Number 9 of Agronomy Series. American Society of Agronomy. Madison, Wisconsin.

DeKeijzer, S., and Hermann, R.K. 1966. Effects of charcoal on germination of Douglas-fir seed. Northw. Sci. 40:155-163.

Fraser, J.W. 1971. Cardinal temperatures for germination of six provenances of white spruce seed. Can. For. Serv. Pub. 1290.

Hermann, R.K., and W.W. Chilcote. 1965. Effect of seedbeds on germination and survival of Douglas-fir. For. Res. Lab., Oreg. State Univ. Res. Pap. No. 4.

International Seed Testing Association. 1985. International rules for seed testing 1985. Seed Sci. & Technol. 13:299-355.

Jackson, M.L. 1958. Soil chemical analysis. Prentice-Hall. Englewood Cliffs, New Jersey.

Keeley, S.C., and Pizzorno, M. 1986. Charred wood stimulated germination of two fire-following herbs of the California chaparral and the role of hemicellulose. Amer. J. Bot. 73:1289-1297.

Kuhnke, D.H., and Brace, L.G. 1986. Silviculture statistics for Canada 1975-76 to 1982-83. Can. For. Serv. North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-275.

Mayer, A.M., and Poljakoff-Mayber, A. 1982. The germination of seeds. Pergamon Press, Toronto.

Moss, E.H. (ed.). 1983. Flora of Alberta. 2nd. ed. Revised by J.G. Packer. University of Toronto. Toronto.

Nie, N.H. 1983. SPSSx User's Guide. McGraw-Hill. Toronto.

Parkson, J.A., and Allen, S.E. 1975. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. Commun. Soil. Science and Plant Analysis. 6(1):1-11.

Sims, H.P. 1968. Effect of water extracts of burned pine duff on germination of jack pine seed. Dept. Environ., Can. For. Serv., Ottawa, Ont. Res. Notes 24(2):18-19.

Sims, H.P. 1976. The effect of prescribed burning on some physical soil properties of jack pine sites in south eastern Manitoba. Can. J. For. Res. 6:58-68.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. (2nd. ed.) McGraw-Hill Book Company. Toronto.

Strong, W.L., and Leggatt, K.R. 1981. Ecoregions of Alberta. Alberta Energy and Natural Resources. Edmonton.

Thomas, R.L. et al. 1967. Comparison of conventional and automated procedures for NPK analysis of plant material using a single digestion. Agronomy J. 59:240-243.

VanLierop, W.M. 1976. Digestion procedures for simultaneous automated determination of NH4, P,K, Ca, and Mg in plant material. Can. J. Soil Sci. 56:425-432.

Viro, P.J. 1974. Effects of forest fire on soil. p.7-46. In: Kozlowski, T.T. and C.E. Ahlgren. (eds.). Fire and Ecosystems. Academic Press. New York.

Wearn, V.H., Springer, E.A. and Lesage, A.J. 1987 Supplement. Forest managers photo guide to prescribed burn planning. Ont. Min. Nat. Res. Kapuskasing, Ont.

Woodard, P.M. 1983. Germination success of *Pinus contorta* Dougl. and *Picea engelmannii* Parry on burned seedbeds. For. Ecol. Manage. 5:301-306.

Woodard, P.M., and G. Cummins. 1987. Engelmann spruce, lodgepole pine and subalpine fir seed germination success on ashbed conditions. Northw. Sci. 61:233-238.

4. SUMMARY

4.1. FIELD STUDY SUMMARY RESULTS

Air (measured at 1.5 cm above mean ground level) and soil (at 0.5 cm below mean ground level) temperature variations of three replications of five microsite types within an upland prescribed burned site were documented and compared to standard meteorological measurements taken in a Stevenson screen.

1. Maximum and average air and soil temperatures were significantly different among microsites over the season studied, but minimum temperatures were not.

2. Weekly maximum temperatures could be consistently ranked from high to low as follows: high albedo open, (HO); low albedo, open, (LO); medium albedo, open (MOSc); low albedo, shaded (LS); high albedo, shaded (HS); and Stevenson Screen (ST).

3. Temperatures of exposed microsites were significantly higher than those of shaded microsites for at least half of the season. All maximum temperatures on exposed sites were higher than those on shaded sites.

4. Only exposed sites had maximum temperatures greater than 50°C. Shaded sites had all temperatures below 45°C whereas temperatures in the Stevenson screen were all less than 33°C.

5. There were few statistical differences among

microsites of similiar sunlight exposure with different albedo types.

6. Generally, there were relatively few changes in the probability of significant differences among microsites when the analysis selected days that were not totally cloud covered.

7. Linear regression of microsite maximum temperatures against Stevenson screen maximum temperatures showed stronger correlations with microsite air temperatures compared to soil measurements. All predicted temperatures for sites near the ground surface were higher than those taken at the Stevenson screen level, especially for exposed sites.

4.2. LABORATORY EXPERIMENTATION SUMMARY RESULTS

The laboratory experiment tested the germination response of two white spruce (Picea glauca (Moench) Voss) seedlots, to four substrate conditions, in five different temperature regimes.

1. Overall the seedlots responded in a similiar pattern but the germination percent for seedlot B was consistently higher than seedlot A, with the exception on fresh ash at the 45°C temperature regime. Also, response differences between seedlot A and B were greatest on

distilled water and least on fresh ash.

2. As temperature increased, germination percent decreased, especially above 35 °C. No seeds germinated in the 48 °C temperature regime, regardless of the seedbed.

3. Both leached and unleached ash decreased seed germination compared to the control. The most marked decreases in germination percentage over that of the control were in ash substrates in temperatures above 35 °C. The germination response for each temperature regime can be ranked (highest to lowest): distilled water (control); leachate; leached ash and fresh ash.

4. As temperature increased, the number of days to fifty percent germination (R_{50} Value) increased, but only significantly when compared to the 45 °C temperature regime.

5. Germination did not appear to be related to treatment-induced pH changes or altered specific conductance of substrates.

6. Solubility of elements examined in fresh ash can be ranked in decreasing order as follows: K, S, Mg, Na, Zn, Mn, Al, P and Fe.

4.3. CONCLUSIONS

The necessarily limited scope of the study requires that several factors be considered before firm management recommendations can be made about the use of fire as a site preparation tool. First, fire in the boreal mixedwood forest is common, and following fire, succession to merchantable stands of white spruce is natural. Second, the microsite temperatures of burned sites were only marginally higher than burned and scarified sites. Third, the environment in this study was limited to an upland prescribed burn in the boreal mixedwood forest, over only one season. And fourth, the laboratory study was limited to one conifer species, and one ash composition.

Results from the present field investigation and laboratory experimentation suggest that we should be cautious about sweeping applications of prescribed burning. Seedbed temperatures after fire can become so hot that conifer germination is unlikely, and ash from burned forest litter reduces conifer seed germination.

4.4. FUTURE FIELD AND LABORATORY INVESTIGATIONS

The results of the microclimate study suggest that there is a need to determine the microclimate of various microsite types based upon aspect and topography. The diurnal patterns of temperatures and the duration of maximum temperatures and soil moisture content also need to be quantified. We must simultaneously examine white spruce germination response to various fire severities. This information would improve the evaluation of the indirect effects of fire. Future investigations should also test conifer response to the effect of artificially and naturally occurring surface materials that may be useful in decreasing soil surface maximum temperatures on susceptible sites.

Future laboratory studies need to isolate the individual constituents in burned residues, and to determine their effects on conifer seed germination. The organic residues demand attention since both the leached and unleached ash were so harmful. In addition, it would be useful to identify the mechanism controlling seed permeability, and to test directly the effect of temperature with the interaction of ash, on soil water movement. Monitoring of seed respiration rates, and seed moisture relationships on different seedbeds at various temperature regimes, will increase our understanding of environmental constraints on seed germination.

LIST OF FIGURES

LIST OF ABBREVIATIONS

Microsite Types

HO: high albedo, open
HOA: high albedo, open, air
HOS: high albedo, open, soil
HS: high albedo, shaded
HSA: high albedo, shaded, air
HSS: high albedo, shaded, soil
LO: low albedo, open
LOA: low albedo, open, air
LOS: low albedo, open, soil
LS: low albedo, shaded
LSA: low albedo, shaded, air
LSS: low albedo, shaded, soil
MOSc: medium albedo, open, scarified
MOScA: medium albedo, open, scarified, air
MOScS: medium albedo, open, scarified, soil
ST: Stevenson Screen
STMAX: Stevenson Screen, maximum temperatures

Canadian Forest Fire Weather Index Codes

FFMC: fine fuel moisture code
DMC: duff moisture code
DC: drought moisture code
ISI: initial spread index
BUI: buildup index
FWI: fire weather index

1. INTRODUCTION TO THESIS

1.1. OVERVIEW

Fire has been used in Canada as a forest site preparation treatment because it has ecological and economic advantages such as: slash abatement, exposing mineral soil, decreasing the need for mechanical scarification or controlling insects and disease (Pyne 1984). However, research in several provinces has demonstrated conflicting results with respect to regeneration of desirable species in postfire environmental conditions (Feller 1982). Hence, forest managers in the boreal forest of Alberta have been hesitant to use fire as a site preparation tool, not only because of the fear of fire escapes, but also because of unknown postburn growth responses peculiar to their region. Since the quantitative and qualitative effects of fire are likely to vary with the nature of the fire and the particular ecological situation (Raison 1979), future justification of the use of prescribed burning in Alberta will require knowledge of the direct and indirect influences of fire on plant growth for each biophysical region.

One indirect effect of fire on plant growth results from the change in microclimate. Ground layer climatic conditions modified by fire show characteristics distinct from other site preparation treatments because of the presence of ash and charred particles. Studies from other regions have reported that soil and air temperatures are higher on burned sites compared to similiar adjacent unburned sites especially during the first few years following burning (Scotter 1963, Sims 1976, Ahlgren 1981, Hungerford and Babbitt 1987).

The importance of altered ground surface temperature has been related to its impact on seed germination (Mayer and Poljakoff-Mayber 1982). Quantification of microclimatic regimes modified by the use of reforestation practices has been limited (Childs and Flint 1987). Microsite albedo characteristics have been generally ignored in forestry, and the benefits of shading by non-conifer vegetation during the first year following fire have not been thoroughly investigated (Thomas and Wein 1985).

The physical and chemical effects of ash on tree seed germination are other factors which must be considered following a fire. The literature pertaining to this area of study is notably limited, and is confounded by questionable methodology and results (Woodard and Cummins 1987). Several laboratory experiments have suggested that the effect of ash on germination may be just as important to tree re-establishment as changes in the microclimate subsequent to burning (Fabricius 1929, Baldwin 1934, Baker 1950, Woodard 1983, Woodard and Cummins 1987).

The purpose of this study was to better understand the physical and chemical mechanisms that influence white spruce (Picea glauca (Moench) Voss)[1] seed germination on burned sites in the boreal mixedwood forest of Alberta. Specifically, the two objectives of interest were: (1) to determine the temperature regimes of different microsites on a burned field site; and (2) to assess the physical and chemical effects of ash and elevated temperatures on white spruce seed germination under controlled laboratory conditions.

This thesis was written in a paper format and consists of four chapters. Chapter one provides a general introduction. Chapter two describes the 1987 summer field study which documented air and soil surface temperature variations of five microsite types within an upland prescribed burned site. Information from this phase of the study was used to justify procedures used in the laboratory experimentation phase. Chapter three describes a laboratory study which tested the effects of burned forest litter and five temperature regimes on white spruce seed germination. The conclusions for chapters two and three are summarized in chapter four. Future research needs are also identified in this chapter.

---

[1] Names of vascular flora as in Moss (1983).

1.2. LITERATURE CITED

Ahlgren, C.E. 1981. Seventeen-year changes in climatic elements following prescribed burning. For. Sci. 27:33-39.

Baker, F.S. 1950. Principles of silviculture. McGraw-Hill Book Co. Toronto.

Baldwin, H.I. 1934. Germination of red spruce. Plant Physiol. 9:491-532.

Childs, S.W., and Flint, L.E. 1987. Effect of shadecards, shelterwoods, and clearcuts on temperature and moisture environments. For. Ecol. and Manage. 18:205-217.

Fabricius, L. 1929. The effect of ashes from forest fires upon germination and early development of plants. Eng. Tr. Forstwiss. Centralblatt. 73:269-276. U.S. For. Serv. Trans. 184.

Feller, M.C. 1982. The ecological effects of slashburning with particular reference to British Columbia: A literature review. B.C. Min. For. Land Manage. Rep. No. 13.

Hungerford, R.D., and Babbitt, R.E. 1987. Overstory removal and residue treatments affect soil surface, air, and soil temperature: implications for seedling survival. USDA For. Serv. Res. Pap. INT-377.

Mayer, A.M., and Poljakoff-Mayber, A. 1982. The germination of seeds. Pergamon Press. Toronto.

Moss, E.H. 1983. Flora of Alberta. 2nd. ed. Revised by J.G. Packer. University of Toronto. Toronto.

Pyne, S.J. 1984. Introduction to wildland fire - fire management in the United States. John Wiley & Sons. Toronto.

Raison, R.J. 1979. Modifications of the soil environment by vegetation fires with particular reference to nitrogen transformations: a review. Plant and Soil 51:73-108.

Scotter, G.W. 1963. Effects of forest fires on soil properties in northern Saskatchewan. For. Chron. 39:412-421.

Sims, H.P. 1976. The effect of prescribed burning on some physical soil properties of jack pine sites in south eastern Manitoba. Can. J. For. Res. 6:58-68.

Thomas, P.A., and Wein, R.W., 1985. The influence of shelter and the hypothetical effect of fire severity on the postfire establishment of conifers from seed. Can. J. For. Res. 15:148-155.

Woodard, P.M. 1983. Germination success of _Pinus contorta_ Dougl. and _Picea engelmannii_ Parry on burned seedbeds. For. Ecol. Manage. 5:301-306.

Woodard, P.M., and Cummins, G. 1987. Engelmann spruce, lodgepole pine and subalpine fir seed germination success on ashbed conditions. Northw. Sci. 61:233-238.

2. SOIL AND AIR SURFACE TEMPERATURES FOR VARIOUS PRESCRIBED BURNED MICROSITES IN THE BOREAL MIXEDWOOD FOREST

2.1. INTRODUCTION

The degree of success in regenerating conifers may be primarily related to the surface energy balance (Hungerford and Babbitt 1987, Oliver et al. 1987, Brand and Janas 1988). The ambient air and soil temperatures of a microsite are especially critical for seed germination and survival; even though other factors such as moisture may be important (Mayer amd Poljakoff-Mayber 1982). In the boreal mixedwood forest of western Canada seedbeds are commonly altered using fire. This treatment reduces the soil organic content and shade debris (slash), or changes the soil surface colour (Rowe 1955, Scotter 1963, Endean 1972, Dobbs and McMinn 1973, Fowler 1974, Sims 1976, Feller 1982). Since microclimate changes following reforestation are generally not understood (Childs and Flint 1987), quantification of ambient air and subsurface soil temperatures on sites affected by fire may contribute to greater conifer regeneration success. Soils of the boreal forest are often considered too cold for optimum conifer growth (Silversides et al. 1986). Certain mechanical site preparation treatments in the boreal forest are routinely selected because of their potential for increasing soil temperature.

Low albedo surfaces such as dark mineral soil, have been used on agricultural lands to hasten snowmelt, or to increase the rate of nutrient release. Dark coloured soils often maintain higher temperatures than high albedo surfaces (Oke 1978).

Data from studies in Manitoba (Sims 1976) and Finland (Viro 1974) have shown that burned surfaces in the boreal forest can become hotter than 50°C. Temperatures are normally higher on burned sites than on adjacent unburned, mechanically prepared areas subjected to comparable conditions (Lesko 1971, Valentine 1975, Sims 1976, Ahlgren 1981, Fowler and Helvey 1981, Hungerford and Babbitt 1987). However, many microclimate studies of burned surfaces have historically used equipment of limited accuracy such as maximum-minimum thermometers (Place 1955, Lavender 1958). Also, the value of most previous studies is limited by periodic sampling over short intervals (Place 1955, Lavender 1958, Waldron 1966, Endean and Johnstone 1974 and Sims 1976. Only a few of these forestry-related studies have attempted to replicate sampling sites (Valentine 1975, Sims 1976, Ahlgren 1981).

The seasonal pattern of temperatures across microsites of different albedos at the soil/air interface have not been documented within a burned site. No known studies have dealt with the effect of shade on the surface temperature of a prescribed burned site during the first year after burning. Also, quantification of microsite temperature differences on burned sites has been restricted to differences between soil surface materials such as humus (Sims 1976) or slash chips (Hungerford and Babbitt 1987). Replicated temperature data for the period of natural white spruce seed, which germinates from June to August throughout most of the boreal (Rowe 1953, Waldron 1966, Zasada and Gregory 1969) will be of value to silviculturalists.

The objective of this study was to document over one summer field season, the air and soil surface temperatures, of five microsite types representative of the variation within an upland prescribed burned site, southeast of Calling Lake, Alberta.

2.2. STUDY AREA

2.2.1. Location and Vegetation

The instrumented study site was approximately 500 m2 in size, and located in a much larger burned area in the Moist Mixedwood Subregion of the Boreal Mixedwood Region (Strong and Leggatt 1981) of Alberta. It was situated approximately 15 km southeast of Calling Lake (113°06′30" W, 55°05′ 30" N) (Fig. 2.1). This subregion is a component of the Interior Plains biophysiographic zone (Rowe 1972). Undisturbed forests in this area are primarily aspen (*Populus tremuloides* Michx.) [2] or balsam poplar (*Populus balsamifera* L.) with lesser amounts of paper birch (*Betula papyrifera* Marsh.). White spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.)B.S.P.) are the dominant conifers. Jack pine (*Pinus banksiana* Lamb.) is not common but dominates drier sites. Shrub associations in the region include a variety of willows (*Salix* spp. L.), dogwood (*Cornus stolonifera* Michx.), and mountain alder (*Alnus tenuifolia* Nutt.) (Strong and Leggatt 1981). Disturbed sites are dominated by wild geranium (*Geranium bicknelli* Britt.), fireweed (*Epilobium angustifolium* L.), coltsfoot (*Paetasites palmatus* (Ai) A. Gray) and marsh reed grass (*Calamagrostis canadensis* Michx.)

---

[2] Names of vascular flora as in Moss (1983).

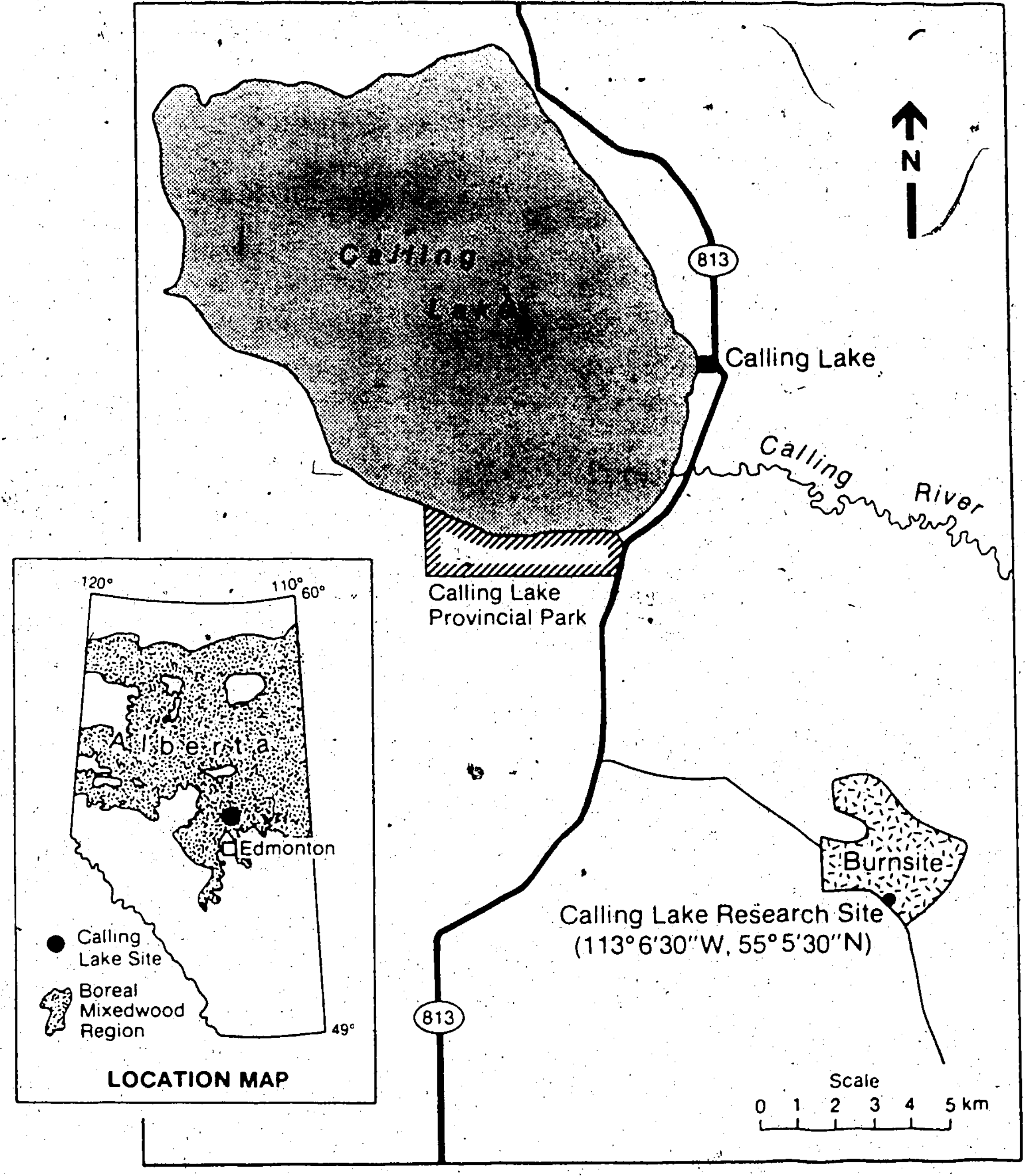


Fig. 2.1. Location of research site near Calling Lake, Alberta, Canada.

2.2.2. Soils

This region was covered by the Laurentide ice sheet during the Wisconsin glaciation (St-Onge 1972). As part of the Alberta Plains, the region is mainly an undulating plain with several isolated areas of rolling to hilly topography (Kjearsgaard 1972). Regional drainage flows by way of the Athabasca River to the Arctic Ocean. Peatlands occupy poorly drained sites throughout the area. Soils of the region are Luvisolic (40%) Organic (25%), Chernozemic (12%), Brunisolic (10%) and Gleysolic (10%) (Kjearsgaard 1972). The study site has been described under the soil subgroup classification of Orthic Gray Luvisol (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978). A complete soil profile description is provided in Appendix I.

2.2.3. Climate

The regional climate is continental, characterized by cold winters, warm summers and generally low precipitation (Kjearsgaard 1972). The mean monthly temperature of the Calling Lake region ranges from -19.8°C in January to 15.9° C in July (Fig. 2.2) (Environment Canada 1980). The extreme maximum temperature during the period May to September has been recorded as 32.2°C, and the extreme minimum is -10°C (Environment Canada 1980). The frost-free period ranges from 65 days to 112 days. Precipitation occurs primarily during the summer months,

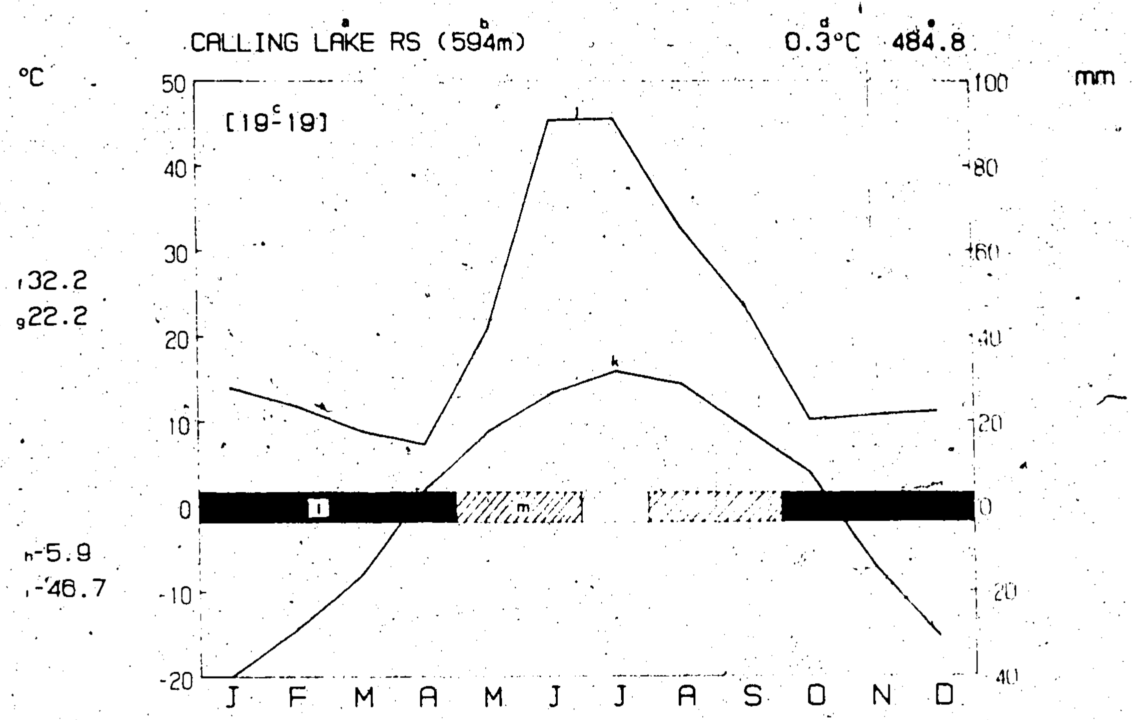


Fig. 2.2. Ecological climate diagram for the Calling Lake Ranger Station (data from Environment Canada 1980). The letters and numbers on the figure indicate the following: a:station; b:height above sea level; c:number of years of observation (temperature - precipitation); d:mean annual temperature; e:mean annual precipitation; f:absolute maximum temperature (highest recorded); g:mean maximum temperature of the warmest month; h:mean minimum temperature of the coldest month; i:absolute minimum temperature (lowest recorded); j:curve of mean monthly precipitation (1 division = 20 mm); k:curve of mean monthly temperature (1 division = 10°C); l:months with mean daily temperature minimum < 0°C; m: months with absolute minimum temperature < 0°C.

varying from a low of 41.8 cm in May to a high of 91.3 cm in July.

2.2.4. HISTORY OF CALLING LAKE BURN

In June of 1984, an area surrounding and including the study site was disturbed by a tornado [3]. Extensive blowdown and tree injury resulted from winds exceeding 200 km/h. The Alberta Forest Service supervised salvage logging operations during the summer of 1985. Approximately 236,000 m3 [4] of timber was removed from about 1350 ha. On August 22, 1986, the site was prescribed burned, in an attempt to reduce machine treatment costs (Fig. 2.3). The burn objectives were to reduce (1) 0-50% of the organic layer, (2) 50-100% of the fine fuels, (3) 0-30% of the volume of downed large fuels, and (4) 50-100% of the live crowns of standing forest cover. The Canadian Forest Fire Weather Index Codes (Canadian Forestry Service 1984) at ignition time (14:30) were: FFMC 85; DMC 51; DC 293; ISI 3; BUI 69; and FWI 10. Organic depths and fuel loadings were not measured prior to or immediately after burning; therefore we have no knowledge of the fire severity. At the time of this study (1987), however, remaining ash and organic layer varied from zero to five cm in depth.

---

[3] The history of the Calling Lake Burn has bee developed from personal communication with Mr. Bill Bereska, Forest Protection Office, Alberta Forest Service, Lac La Biche Provincial Forest, Lac La Biche, AB.

[4] This value was converted from 50 million FBM to m3 using equations described by Weneger (1984).

Fig. 2.3. Site conditions following the effects of the tornado and burning at the Calling Lake research site.

2.3. METHODS

2.3.1. General

The temperature variations for three replicates of five microsite types were monitored from June 11 (Julian Day 162) to September 12 (Julian Day 255) during 1987 (Fig. 2.4). The five microsite types studied were described as (1) low albedo, open (LO) (Fig. 2.5), (2) low albedo, shaded (LS) (Fig. 2.6), (3) high albedo, open (HO), (4) high albedo, shaded (HS), and (5) medium albedo, open, scarified (MOSc) (Fig. 2.7). A microsite was selected on the basis of a level, uniform coloured surface that was at least 1 m in diameter. The three replicates of the scarified type only, were created by spading the top layer of soil surface and exposing mineral soil. The albedo types were classified as high, medium or low according to the soil surface colour. A Munsell soil colour chart was used to describe the soil colour: 7.5YR5/1 for high albedo sites; 10YR7/2 for medium albedo sites, and 10YR1.7/1 for low albedo microsites. Shaded microsites were covered with a white painted 30x30 cm open-sided, wooden shelter, supported 15 cm in height (Fig. 2.4). Vegetation within each microsite was removed throughout the season.

Temperatures for all microsites were recorded 1.5 cm above and .5 cm below the soil surface by means of thermocouples and thermistors. Recording sensors were

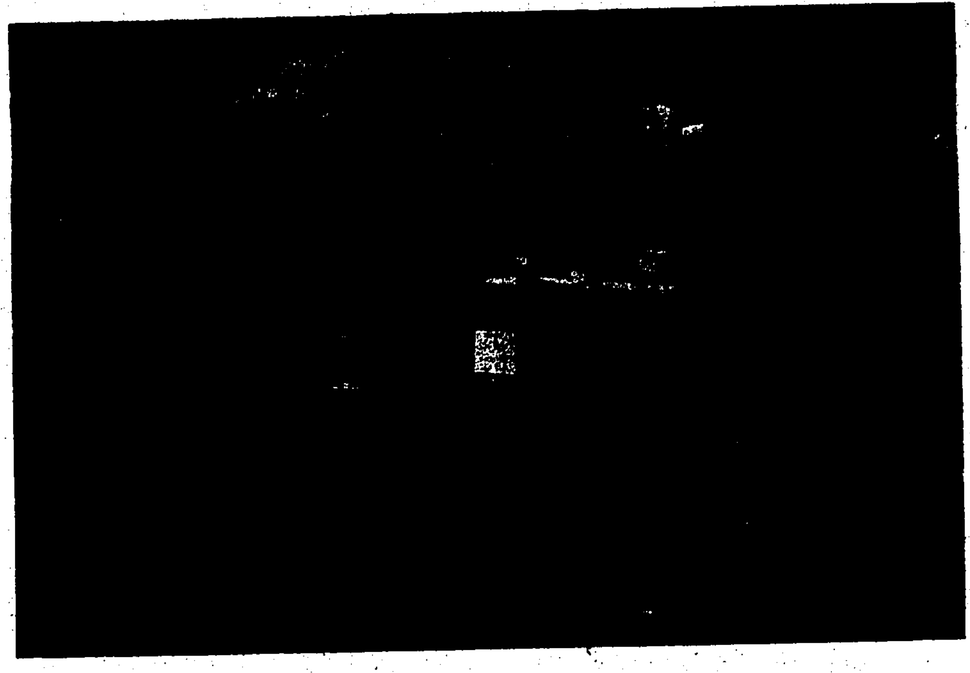


Figure 2.4. General setup of meteorological instruments at Calling Lake burn, 1987.

Figure 2.5. Thermocouple at low albedo, open (LO) microsite.

Figure 2.6. Thermocouple at low albedo, shaded (LS) microsite.

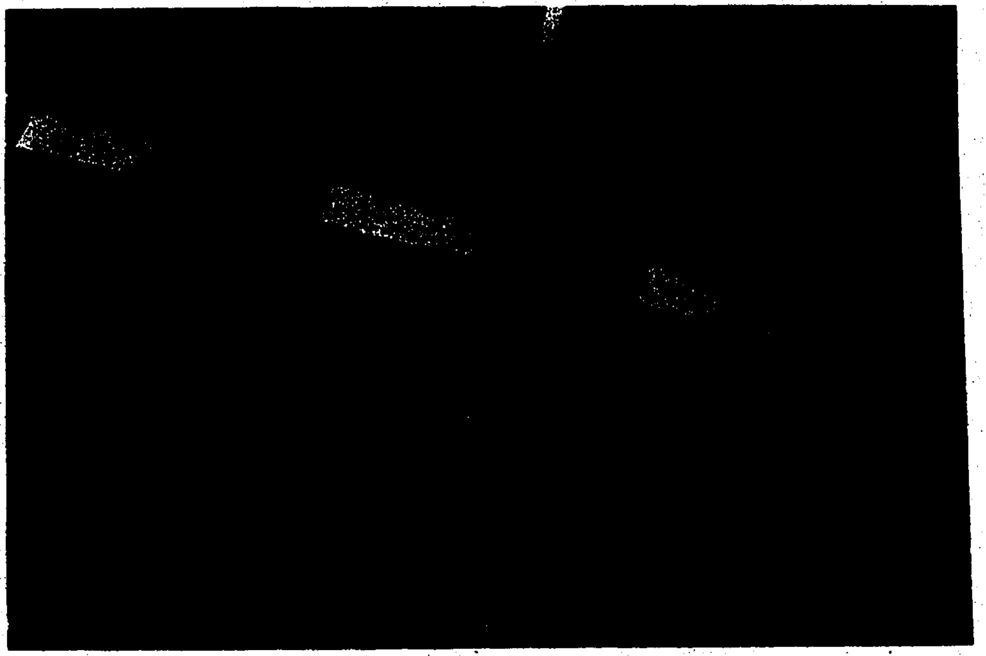


Figure 2.7. Thermocouple at medium albedo, open, scarified (MOSc) microsite.

positioned so that temperature measurements were representative of the physical environment experienced by the white spruce seed most likely to germinate (Moore and Wein 1977).

A 1.2 m high Stevenson screen (ST) was established within the study site and used to correlate standard weather data with microsite air and soil temperature data. It was oriented north in keeping with standard weather collection procedures.

Temperature was recorded every minute, and summarized as daily average, maximum and minimum values using programable data loggers (three model CR21's and one model 21X; of Campbell Scientific Inc., Logan, UT). All sensors were calibrated prior to placement in the field. The data were transferred by magnetic tape to the University of Alberta computer system for storage. SPSSx (release 2.2, Nie 1983) was used for processing, and Lotus 1-2-3 (release 2.10, Lotus Development Corporation, Cambridge, MA) was used to sort the data.

Two soil profiles were described within the study area to confirm the soil description by the Canadian Soil Survey Committee, Subcommittee on Soil Classification (1978). Rainfall within the study area was collected from two standard gauges on approximately a weekly basis.

2.3.2. Statistical Analyses

A model of analysis of variance (ANOVA) for repeated measures was used to analyze the data (Milliken and Johnson 1984). The analyses were based upon three replications of two types of temperature measurement (air and soil) for five microsite types (HO, HS, LO, LS, and MOSc). Sampling date by week and by day were the independent variables, while average, maximum and minimum temperatures were the dependent variables. Groups were tested for homogeneity of variance prior to attempting the ANOVA. Greenhouse-Geisser adjustments were used to test sphericity of the variance and covariance matrix (Milliken and Johnson 1984). ANOVA tests for daily and weekly periods were completed on the dependent variables. Duncan's multiple range test on a weekly basis at a 5% probability level was then applied.

ANOVA on a weekly basis was also used to compare temperature differences among microsites on days not totally cloud covered. These days were selected from noon fire weather observations taken by the Alberta Forest Service at the Calling Lake Ranger Station.

Correlation and linear regression analyses (Steel and Torrie 1980) were used to relate maximum temperatures of three replications of air and soil microsite types to maximum temperatures recorded by instruments in the Stevenson screen.

2.4. RESULTS

2.4.1. Comparison to Climate Normals

The maximum ambient air temperatures for the 1987 Calling Lake area were slightly higher than normal for June (+1.3°C) and July (+.5°C), and lower than normal for August (-2.3°C). Precipitation for the region was lower than normal for June (-53.7 mm) and July (-61.5 mm), but higher than normal for August (+49.3 mm) (Atmospheric Environment Service 1988). The total amount of rainfall averaged from two rain gauges on the study site, from June 4 to September 12 was 218.2 mm, which was approximately 30 mm less than normal for that period.

2.4.2. Average, Maximum and Minimum Temperatures of Microsites

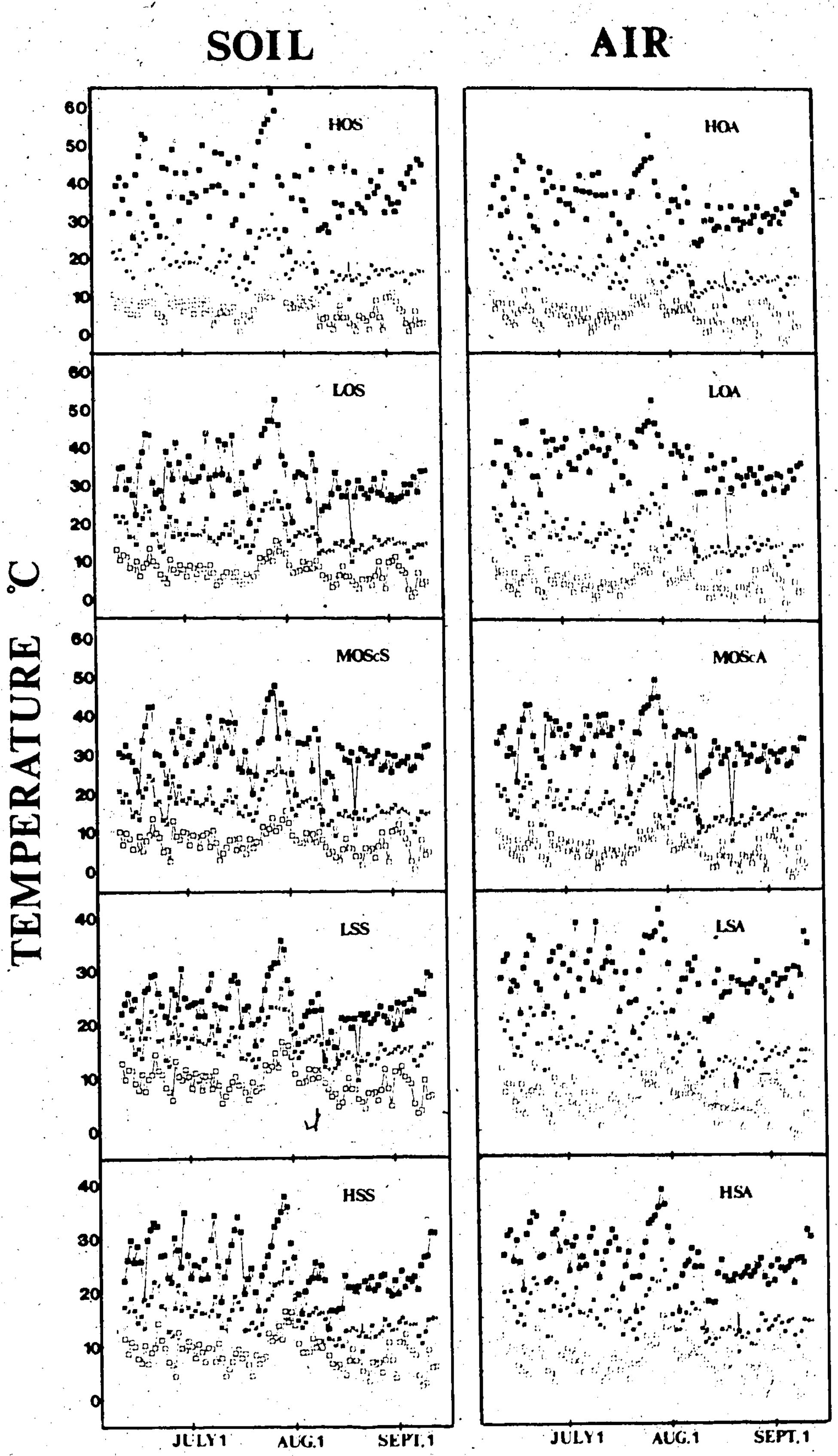
Overall, weekly maximum temperatures and weekly average temperatures were significantly different among the five microsite types (p=0.00002, and p=0.00385, respectively), but minimum temperatures were not (p=0.27319). These levels of significance changed only marginally when days that were not totally cloud covered were analyzed (Appendix II).

Multiple comparison analyses among the different microsite types for the entire data set showed that there were virtually no differences among minimum temperatures recorded, while average temperatures were sometimes significantly different among microsites. The greatest differences among microsites were shown by the Duncan's multiple comparisons of maximum weekly temperatures (Appendix III).

The maximum temperatures of the exposed sites were significantly greater ($p<0.05$) than shaded microsites for all weeks such that: LO>HS; HO>LS; HO>HS and MOSc>HS; and for 12 out of 13 weeks for LO>LS, and MOSc>LS. In addition, temperatures higher than 30°C occurred more frequently on open (unshaded) microsites than on shaded microsites (Fig. 2.8). For example, temperatures of the high albedo, shaded, soil (HSS) microsite type, exceeded 30° C on 16 out of 93 days, but were never greater than 40°C. The maximum temperatures for the high albedo, open, soil (HOS) microsite type, however, were greater than 30°C for 78 days of the season recorded and of those, temperatures were greater than 40°C for 42 days, eight of those days which exceeded 50°C. Only open (unshaded) microsite types produced temperatures greater than 50°C. Shaded site types did not register maximum temperatures greater than 45°C.

There were few significant differences in temperature among microsites of different albedo types, with similiar sunlight exposure. Different albedo microsite types had maximum temperatures that were statistically different from each other for only a few weeks: HS>LS for two weeks; HO>LO for one week; and HO>MOSc for three weeks. Differences among average temperatures were even lower. These results

Fig 2.8. Daily average(✱), maximum (■), and minimum (□) temperatures for the averages of three replicates of the following microsite types: high albedo, open, soil (HOS); high albedo, open, air (HOA); low albedo, open, soil (LOS); low albedo, open, air (LOA); medium albedo, open, scarified, soil (MOScS); medium albedo, open, scarified, air (MOScA); low albedo, shaded, soil (LSS); low albedo, shaded, air (LSA); high albedo, shaded, soil (HSS); and high albedo, shaded, air (HSA).


SOIL
AIR
TEMPERATURE °C
HOS
HOA
LOS
LOA
MOScS
MOScA
LSS
LSA
HSS
HSA
0
10
20
30
40
50
60
JULY1
AUG.1
SEPT.1

did not change significantly when only days not totally cloud covered were analyzed. Also, minimum air and soil temperatures were not different among microsites of different albedo types.

Weekly maximum air and soil temperatures were consistently ranked from high to low as follows: HO; LO; MOSc; LS; and HS. (The exceptions to this consistent ranking were minimal: LO>HO for week 8, but not significantly; and HS>LS for three weeks, but not significantly). When days which were not totally cloud covered were selected, maximum air and soil temperatures were ranked as HO; LO; MOSc; LS; AND HS, but the average weekly maximum temperatures were higher.

Air temperatures were significantly different from soil temperatures for average and minimum recordings but not maximum recordings. Minimum soil temperatures were significantly higher than minimum air temperatures for all weeks analyzed with and without selection of sunny days.

The highest recorded daily maximum temperature, averaged from three replicates of the HO soil microsite type, was 63.7°C on July 29. The lowest recorded daily minimum temperature, averaged from three replications of the HO air microsite type, was -2.4°C on September 8 (Fig. 2.8).

2.4.3. Temperature Comparison of Microsites to Standard Weather Shelter (Stevenson Screen).

Maximum daily temperatures recorded at the Stevenson screen were all less than 33°C (Appendix IV). In addition, they were always less than the maximum daily temperatures of the five microsite types (HO, LO, HS, LS and MOSc). Linear regression of the maximum temperatures for each microsite type, against Stevenson screen maximum temperatures, indicated that Stevenson screen measurements were better predictors of surface air temperatures than soil temperatures (Appendix V). Correlation coefficients for all relationships ranged between 0.69 and 0.87.

Predicted microsite temperatures were all higher than the Stevenson screen (Appendix V). The predicted temperatures of unshaded sites were especially higher than Stevenson screen temperatures. For example, the equation predicting temperatures for the open, scarified (MOSc) microsite type showed that the air directly above the soil surface would likely reach temperatures in excess of 43°C when 30°C was recorded at Stevenson screen height. On a shaded site, such as the high albedo, shaded (HS) microsite, regression equations predicted that the air temperature would reach only 34°C. Refer to Appendix V for equations.

2.5. DISCUSSION

The extremely high maximum air and soil temperatures of the open microsites can be expected to have a large impact upon biological processes at the soil surface. While it may be that some boreal sites are too cold for optimum forest growth (Viereck and Schandelmeier 1980), temperatures recorded on the upland burned site indicated that open microsite temperatures were frequently greater than the average optimum temperature of 24°C for germination of boreal conifers (Arnott 1973). These high temperatures were due primarily to the lack of shading, and therefore higher radiation. Temperatures greater than 50°C such as recorded on the open sites, will have a negative effect upon white spruce germination (see Chapter 3). Note that the magnitude of these temperature differences is often not detected by standard weather observations.

Temperature differences between shaded and open sites were much greater than between albedo types. The similiarity among the open microsite types of distinctly different surface colours was not expected because studies in agriculture and microclimatology have reported marked differences in soil temperature depending upon surface colour (Waggoner <u>et al</u>. 1960, Hillel 1977, Haynes 1987).

Results of the ANOVA indicated that there was an interaction between microsite (LO, LS, HO, HS, and MOSc) and type (air and soil) for maximum temperatures. Thus, the overall effect of the albedo was different for air and soil temperatures. Daily maximum air temperatures of the open, high albedo site types were expected to be higher than the daily maximum soil temperatures; and daily maximum soil temperatures of the open, low albedo site type were expected to be higher than the air temperatures due to physical property differences. Actual temperatures recorded in this study did not reflect this.

The temperature similiarity among open microsites may be partially explained by the variability in organic matter thickness both among and within microsite type. Among the high albedo, open replicates, the organic depth varied from 0.0 cm to 2.0 cm, and 1.5 cm to 4 cm in the low albedo type. The seasonal variation in moisture content of these layers and the resulting variation in heat capacity and conductivity may have been sufficient to confound the results, and override the effects of albedo type.

Significant differences between air and soil average and minimum temperatures seemed realistic, given the differences in heat capacity and thermal conductivity properties of these environments. The fact that the sensor in the Stevenson screen recorded the lowest maximum air temperatures compared to the readings at each of the microsite types was due primarily to local advection and vertical variation in the air. Temperatures recorded in the Stevenson screen clearly represented larger horizontal areas and therefore averaged out the effect of microstructure variations of the surface and are subjected to greater ventilation effects (McHattie and McCormack 1961).

The maximum temperatures on the scarified (MOSc) microsite type were logically higher than those of the shaded sites due to differences in the radiation. However, the maximum temperatures of air and soil combined on this site type were expected to have increased surface temperatures during the night, and reduced temperatures during the day compared to the low albedo microsite type due to several facts: differences in albedo types; increases in soil porosity, and decreases in the thermal conductivity and heat capacity by scarification (Ghildyal and Tripathi 1987). Since maximum temperatures recorded on the MOSc microsite type were not statistically different than the LO microsite type, other factors such as moisture may have affected these results.

Shade appears to be the best agent to ameliorate extreme temperatures on burned sites. Hence, shelters (Alexander 1984, Thomas and Wein 1985, Childs and Flint 1987) and vegetative covers (Lavender 1958, Fowler and Helvey 1978, Thomas and Wein 1985, Childs and Flint 1987, Hungerford and Babbitt 1987) might reduce soil-air interface temperatures. However, economic feasibility and competition with seedlings, are factors that also must be considered.

2.6. LITERATURE CITED

Ahlgren, C.E. 1981. Seventeen-year changes in climatic elements following prescribed burning. For. Sci. 27: 33-39.

Alexander, R.R. 1984. Natural regeneration of Engelmann spruce after clearcutting in the central Rocky Mountains in relation to environmental factors. USDA For. Serv. Res. Pap. RM-254.

Arnott, J.T. 1973. Germination and seedling establishment. p. 55-66. In: Cayford, J.H. (ed.). Direct seeding symposium. Dept. of the Environ. Can. For. Serv. Pub. No. 1339. Ottawa.

Atmospheric Environment Service. 1988. 1987 climatic data for the Calling Lake Region. Unpublished statistics. AES. Edmonton, Alberta.

Brand, D.G., and Janas, P.S. 1988. Growth and acclimation of planted white pine and white spruce seedlings in response to environmental conditions. Can. J. For. Res. 18: 320-329.

Canada Soil Survey Committee, Subcommittee on Soil Classification. 1978. The Canadian system of soil classification. Can. Dept. Agric. Publ. 1646. Supply and Services Canada. Ottawa, Ont.

Canadian Forestry Service. 1984. Tables for the Canadian Forest Fire Weather Index. 4th ed. Environ. Can., Can. For. Serv. Forest. Tech. Rep. No. 25.

Childs, S.W., and Flint, L.E. 1987. Effect of shadecards, shelterwoods, and clearcuts on temperature and moisture environments. For. Ecol. Manage. 18:205-217.

Dobbs, R. C., and McMinn, R.G. 1973. The effects of site preparation on summer soil temperatures in spruce-fir cutovers in the British Columbia Interior. Reprint from Can. Dept. Environ., Forest. Serv. Bi-Monthly Res. Note. 29:6-7.

Endean, F. 1972. Soil temperature, seedling growth and white spruce regeneration. p. 15-20. _In_: McMinn, R.G. (ed.). White spruce: the ecology of a northern resource. Proc. of symposium, June 21, 1971. Canadian Botanical Association, Edmonton, Alberta. North. For. Res. Cent., Can. For. Serv. Dept. of Environ. Info. Rep. NOR-X-126.

Endean, F., and Johnstone, W.D. 1974. Prescribed fire and regeneration on clearcut spruce-fir sites in the foothills of Alberta. CFS-NFRC. Edmonton, Infor. Rep. NOR-X-126.

Environment Canada. 1980. Canadian climate normals: temperature and precipitation. 1951-1980. Prairie Region. Atmos. Environ. Serv.

Feller, M.C. 1982. The ecological effects of slashburning with particular reference to British Columbia: a literature review. B. C. Min. For. Land Manage. Rep. No. 13.

Fowler, W.B. 1974. Microclimate. p. 1-18. In: Cramer, O.P.,(ed.). Environmental effects of forest residues management in the Pacific Northwest: a state of knowledge compendium. USDA For. Serv. Gen. Tech. Rep. PNW-24.

Fowler, W.B., and Helvey, J.D. 1978. Changes in the thermal regime after prescribed burning and select tree removal. USDA For. Serv. Res. Pap. PNW-234.

Fowler, W.B., and Helvey, J.D. 1981. Soil and air temperature and biomass after residue treatment. USDA For. Serv. Res. Note PNW-383.

Ghildyal, B.P., and Tripathi, R.P. 1987. Soil physics. John Wiley and Sons. Toronto.

Haynes, R.J. 1987. The use of polyethylene mulches to change soil microclimate as revealed by enzymatic activity and biomass nitrogen, sulphur, and phosporous. Biol. Fertil. Soils 5: 235-240.

Hillel, D. 1977. Computer simulation of soil-water dynamics: a compendium of recent work. IDRC. Ottawa.

Hungerford, R.D., and Babbitt, R.E. 1987. Overstory removal and residue treatments affect soil surface, air, and soil temperature: implications for seedling survival. USDA For. Serv. Res. Pap. INT-377.

Kjearsgaard, A.A. 1972. Soil survey of the Tawatinaw map sheet (83-I). Alberta Institute of Pedology Rep. No. S-72-29.

Lavender, D.P. 1958. Effect of ground cover on seedling germination and survival. State of Oregon. Forest Lands Research Center. Res. Note No. 38.

Lesko, G.L. 1971. Early effects of a prescribed fire in spruce-fir slash on some soil properties. Can. Dept. Fish. and For. Can. For. Serv. Unpublished Internal Rep. A-44.

Mayer, A.M., and Poljakoff-Mayber, A. 1982. The germination of seeds. Pergamon Press. Toronto.

McHattie, L.B., and McCormack, R.J. 1961. Forest microclimate. A topographic study in Ontario. J. Ecol. 49:301-323.

Milliken, G.A., and Johnson, D.E. 1984. Analysis of messy data. Vol.I: designed experiments. Lifetime Learning Publications. Toronto.

Moore, J.M., and Wein, R.W. 1977. Viable seed populations by soil depths and potential site recolonization after disturbance. Can. J. Bot. 55: 2408-2412.

Moss, E.H. 1983. Flora of Alberta. 2nd. ed. Revised by J.G. Packer. University of Toronto. Toronto.

Nie, N.H. 1983. SPSSx User's Guide. McGraw-Hill. Toronto.

Oke, T.R. 1978. Boundary layer climates. Methuen & Co. New York.

Oliver, S.A., Oliver, H.R., Wallace, J.S., and Roberts, A.M. 1987. Soil heat flux and temperature variation with vegetation, soil type and climate. Agric. For. Meteorol. 39:257-269.

Place, I.C.M. 1955. The influence of seedbed conditions on the regeneration of spruce and balsam fir. Can. Dept. North. Aff. Nat. Res. For. Br. For. Res. Div. Bull. 117.

Rowe, J.S. 1953. Delayed germination of white spruce on burned ground. Can. Dept. Res. and Dev. For. Br. For. Res. Div. Silv. Leaflet No. 84.

Rowe, J.S. 1955. Factors influencing white spruce reproduction in Manitoba and Saskatchewan. Dept. North. Aff. and Nat. Res. For. Br. For. Res. Div. Tech. Note. No. 3.

Rowe, J.S. 1972. Forest regions of Canada. Can. For. Serv. Pub. 1300.

Scotter, G.W. 1963. Effects of forest fires on soil properties in northern Saskatchewan. For. Chron. 39:412-421.

Silversides, R.H., Taylor, S.W., and Hawkes, B.C. 1986. Influence of prescribed burning on seedling microclimate and its potential significance in northern interior British Columbia. Proc. Forest Climate '86 Symposium/Workshop on climate applications in forest renewal and production, held at Orillia, Ontario. Nov. 17-11, 1986. Sponsored by Can. For. Serv. Atmos. Env. Serv. and Ont. Min. Nat. Res.

Sims, H.P. 1976. The effect of prescribed burning on some physical soil properties of jack pine sites in south eastern Manitoba. Can. J. For. Res. 6: 58-68.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. (2nd. ed.) McGraw-Hill Book Company. Toronto.

St.-Onge, D.A. 1972. Tawatinaw map-area geology. p.93-99. In: A.A. Kjearsgaard. 1972. Reconnaissance soil survey of the Tawatinaw map sheet (83-I). Alberta Institute of Pedology, Rep. No. S-72.

Strong, W.L., and Leggatt, K.R. 1981. Ecoregions of Alberta. Alberta Energy and Natural Resources. Edmonton.

Thomas, P.A., and Wein, R.W. 1985. The influence of shelter and the hypothetical effect of fire severity on the postfire establishment of conifers from seed. Can. J. For. Res. 15:148-155.

Valentine, J.M. 1975. Site preparation effects on microclimate and Douglas-fir seedling growth. Ph.D. Thesis. University of Washington. Seattle.

Viereck, L.A., and L.A. Schandelmeier. 1980. Effects of fire in Alaska and adjacent Canada - a literature review. U.S. Dept. Int. Bur. Land Manage. Alaska State Office. B.L.M.-Alaska Technical Report 6.

Viro, P.J. 1974. Effects of forest fire on soil. pp. 7-46. In: Kozlowski T.T. and C.E. Ahlgren (eds.). Fire and Ecosystems. Academic Press. New York.

Waggoner, P.E., Miller, P.M., and De Roo, H.C. 1960. Plastic mulching principles and benefits. Bull. No. 634. Conn. Agr. Expt. Sta. New Haven.

Waldron, R.M. 1966. Factors affecting natural white spruce regeneration on prepared seedbeds at the Riding Mountain Experimental Area, Manitoba. For. Br. Dept. Pub. No. 1169.

Weneger, K.F. (ed.). 1984. Forestry handbook (2nd ed.). John Wiley and Sons. Toronto.

Zasada, J.C., and Gregory, R.A. 1969. Regeneration of white spruce with reference to interior Alaska: a literature review. USDA For. Serv. Res. Pap. PNW-79.

3. WHITE SPRUCE SEED GERMINATION RESPONSE TO HIGH TEMPERATURE REGIMES ON ASHED FOREST LITTER

3.1. INTRODUCTION

Natural and artificial seeding are important methods of regenerating white spruce in Alberta. Until recently, it has accounted for as much as 52% of the white spruce re-establishment in this province (Kuhnke and Brace 1986). Common seedbeds for white spruce regeneration in Alberta are wildfire sites and, increasingly, slash-burned areas. Previous studies (Viro 1974, Sims 1976) and observation from the present study (Chapter 2) have indicated that surface layers of burned sites in the boreal forest can become quite hot; summer temperatures greater than 60°C on exposed sites were recorded. Despite this information, results from unburned mechanically scarified sites have shown that the average optimal temperature for germination of coniferous species in the boreal forest may be 24°C (Arnott 1973). In a laboratory study, Fraser (1971) determined that on standard seedbed media (filter paper), temperatures above 38°C were detrimental to white spruce germination.

Recent information suggests that ash, charred material and charcoal may also have an important impact on seed germination but there is much conflicting evidence about the effect of ash residues (as reviewed by Woodard and Cummins 1987). Overall the studies above provided limited documentation of the type and concentrations of fire residues. In all cases, results seemed to be influenced by methods, statistical designs, tree species tested and even populations of seeds within species. The effect of the ash and i'ts interaction with high temperatures on conifer seed germination had not previously been directly addressed. White spruce was one species that had yet to be tested in controlled conditions. Therefore, the objective of this experiment was to test the success of white spruce (<u>Picea glauca</u> (Moench) Voss)[5] seed germination on seedbeds derived from ashed forest litter, over a range of high temperature environments.

---

[5] Names of vascular flora as in Moss (1983).

3.2. MATERIALS AND METHODS

3.2.1. General

Pilot studies were conducted to standardize the procedures used in the experiment described here. Refer to Appendix VI for further details. This experiment was carried out in five separate growth rooms of the phytotron, Department of Botany, University of Alberta, Edmonton. Air temperatures were held constant at 20°C for 22 hours in all growth rooms. Each of the five growth rooms was randomly assigned constant maximum temperatures for two hours. These maximums were: 30°C; 35°C; 40°C; 45°C and 48°C. These temperature regimes were selected to artificially recreate temperature regimes of burned field sites with peak daytime heating. The photoperiod was based on a 16-hour day and 8-hour night, to represent summer field conditions.

Burned residues used in this experiment, were created by combusting 90% by weight of surface organic material collected from the Boreal Mixedwood region (Strong and Leggatt 1981). The unburned organic material consisted of forest floor organic material (46.1%), balsam poplar branches less than 10 cm in diameter and rotting aspen bark (32.6%), live (5.3%) and dead (15.9%) white spruce branches less than 3 cm in diameter.

All tests were performed in clear 9 cm diameter petri dishes on Kimpak[6]. Four seedbed media were used. The control medium was 30 ml of distilled water. The second medium consisted of 30 ml distilled water plus 1.5 g fresh ash. The amount of fresh ash per petri dish surface area was equivalent to 2.36 t/ha of residue left after 90% fuel consumption of 23.6 t/ha. This is reasonable for upland burns in the boreal mixedwood forest (Wearn et al. 1987 Supplement). The quantity per petri dish was less than the amount of ash that normally remains on a cutover where the slash is piled and burned. A third seedbed medium consisted of 30 ml of distilled water plus 1.4662 g leached ash. This amount of leached ash per petri dish was equivalent to 1.5 g of fresh ash minus the weight of ash lost during leaching. The leached ash seedbed was designed to mimic prescribed burned residue following spring runoff. This treatment was incorporated into the experimental design to distinguish between the chemical and physical effects of ash. The leached ash substrate was obtained by washing 10 g of fresh ash, ten times with 25 ml of distilled water over several hours, through Whatman #2 filter paper. The fourth medium was 30 ml of leachate that was collected during the previous leaching process. This was used to examine the effect of the soluble chemical component of the ash.

Two sets of chemical analyses were completed. They were designed to test the chemical constituents of the

---

[6] Kimpak is a multilayered absorbent material, produced by Seedburo Equipment Company, (Kimberly Clark), Chicago, Illinois.

seedbed ash, and to determine the elements released into solution during the course of the experiment. Specific conductance was used to compare the total concentration of soluble components in the seedbed media.

First, fresh ash and leached ash were analyzed after total digest by peroxidation (Parkinson and Allen 1975, Van Lierop 1976, Thomas et al. 1967)) by the Department of Soil Science, University of Alberta. The following elements were analyzed: N, P (by Technicon Auto-Analyzer II Industrial Method #334-74W/Bt), K, Na, Mg, Ca, Mn, Fe, and C (Analytical Methods for AAS 0993-8039 1982). The pH and specific conductance at 25°C were done on a separate sample extracted from a saturated paste (Black 1965).

The second analysis was on the soluble components of the three seedbed media: 1) the leachate, 2) the 1.5 g of fresh ash in 30 ml of distilled water; and 3) the 1.4662 g of washed ash in 30 ml of distilled water. The latter two were allowed to equilibrate for 24 hours at 20°C, and were then filtered through Whatman #2 filter paper prior to analysis. This was completed by the soil science laboratory at the Northern Forestry Centre, Canadian Forestry Service in Edmonton. The analysis measured total N by Keldjal (Jackson 1958) P, K, Ca, Na, Mg, Mn, Al, Fe, S, Zn, by inductively coupled argon plasma (ICP; Applied Research Laboratory, 34000 Vacuum); and pH and specific conductance (Black 1965).

Two different white spruce seedlots from approximately the same latitude (55°N) were provided by Pine Ridge Nursery, Smokey Lake, Alberta. Seedlots were cleaned of debris and light seeds using a North Dakota blower and counted into each dish using an electronic seed counting device. Appendix VII presents a complete description of the seedlot specifications.

Six replicates of 40 seeds per seedlot were randomly sown on the petri dishes, containing one of the four seedbed types for each temperature regime. Seeds were stratified on these seedbeds for 21 days at 3-5°C, following with the International Seed Testing Association (1985) regulations. The procedure did not disturb seeds following stratification, and imitated either a fall burn and early spring seeding, or a spring burn and early seeding. The petri dishes were then randomly placed in the growth rooms for 21 days; the duration of the germination test period prescribed by the International Seed Testing Association (1985) regulations. Positions of the petri dishes in the growth rooms were changed every second day. Moisture conditions were checked on a daily basis. Distilled water was added to petri dishes as required to maintain a moist seedbed, and high relative humidity.

Starting after day seven each petri dish was examined for seed germination. The examination time was constant between days. Seeds were considered germinated when the radicle extended four times the length of the seed. Once germinated, seeds were removed from the petri dish. At the end of the duration of the experiment, all ungerminated seeds on the distilled water were cut to ensure that low germination responses on particular substrates were not only due to empty seeds. Few seeds were empty. Statistical analyses were based on the responses of all 40 seeds per petri dish.

3.2.2. Statistical Analyses

A three-way factorial experiment was conducted based upon two seedlots, four substrates, four temperature regimes, and six petri dishes per treatment. In order to complete the factorial analysis it was assumed that individual growth rooms were not exerting an influence on germination response, extraneous to the designated temperature regimes. Since no seeds germinated in the 48°C temperature regime, this treatment was eliminated from the final analysis.

The independent variables were substrate type, temperature, and seedlot. The dependent variables were: percent germination per petri dish; and the number of days to 50% germination (R_{50} Value). The arcsin $\sqrt{p}$ (p=germination percent/100) transformation of germination percent was used to satisfy the assumption of normal distribution (Steel and Torrie 1980). Analysis of variance using the SPSSx package (release 2.2, Nie 1983) was conducted on transformed and untransformed data to test for significant differences among the main effects, the two-way and the three way interactions among the levels of seedlot, substrate and temperature. Scheffe's multiple comparison test at 5% probability test was then applied.

3.3. RESULTS

3.3.1. Percent Germination

All main effects and the two-way interactions of seedlot by substrate, and temperature by substrate, were significant at alpha<.05 for transformed germination percent data (Table 3.1). Three-way interactions of seedlot by temperature by substrate were not significant.

3.3.1.1. Seedlot

Overall, the percentage of seeds which germinated differed significantly between seedlots (p=0.00004). In addition the two seedlots responded in a similiar pattern to the different substrates and temperature. For example, as temperature increased germination percent response decreased. But there was a significant interaction between seedlot and substrate (p=0.04425, Table 3.1). Differences between seedlots were greatest on distilled water and least on fresh ash (Fig. 3.1). Germination percent for seedlot B was always higher than seedlot A, with the exception of fresh ash at the 45°C temperature regime.

3.3.1.2. Temperature and Substrate

As temperature increased, germination percent decreased (Fig. 3.1). All germination percent responses for temperature treatments (excluding the 48°C treatment) were

Table 3.1. Summary of ANOVA for transformed (arcsin$\sqrt{p}$) germination data.

Part of Model	F-Ratio	DF	Prob.
Grand Mean	5987.85	1.0	0.00000
Seedlot	17.91	1.0	0.00004
Temperature	469.89	3.0	0.00000
Substrate	213.52	3.0	0.00000
Seedlot*Temperature	1.37	3.0	0.25435
Seedlot*Substrate	2.76	3.0	0.04425
Temp*Substrate	3.67	9.0	0.00034
Seedlot*Temp*Substrate	0.80	9.0	0.62134

Note: The 48°C treatment was not included in this analysis.

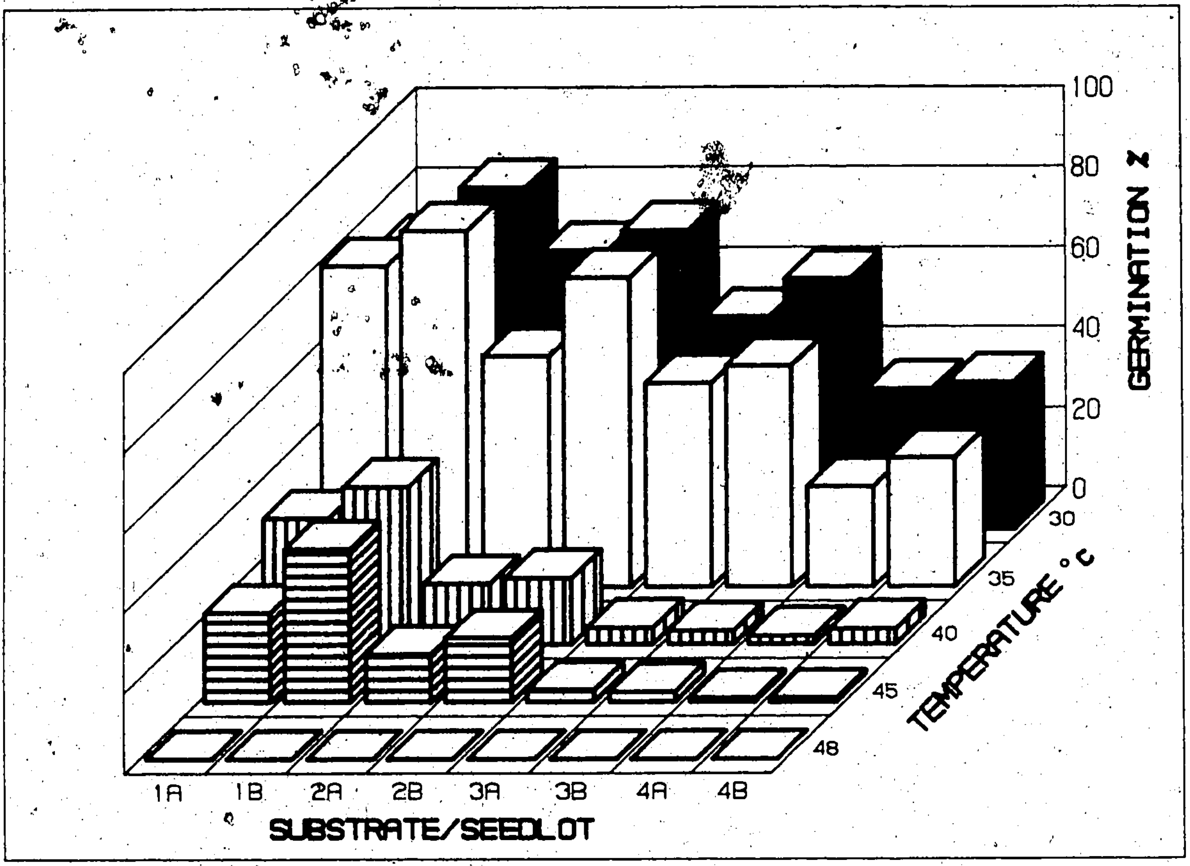


Fig. 3.1. Germination response for seedlots A and B, for four substrates (1=distilled water, 2=leachate, 3=leached ash, and 4=fresh ash), subjected to five temperature regimes (30°C, 35°C, 40°C, 45°C, 48°C).

significantly different except between 30°C and 35°C, and between 40°C and 45°C, for each substrate (Table 3.2). Within each of these temperature groupings (30 and 35°C, and 40 and 45°C), there was a second obvious trend among substrates.

The germination success on the four media can generally be ranked (highest to lowest): distilled water, leachate, leached ash and fresh ash (Fig. 3.1 and Table 3.3). Response on leachate was slightly lower than the response on distilled water, but only significantly in the 40°C regime. The results demonstrated that ash, whether leached or unleached, reduced white spruce germination compared to the control. For example, average germination response of seedlot B on fresh ash was only 37% compared to 85% in distilled water in the lowest temperature environment (Fig. 3.1).

Lowest germination percent responses were recorded on fresh (unleached) ash. The germination percent response on fresh ash was significantly different from all other substrates in the lower temperatures, but not in the 40°C and 45°C regimes (Table 3.3). At these higher temperatures, germination percent response was similiar to leached ash. For 30°C and 35°C, the germination on the leached ash was significantly lower than on the distilled water, but not lower than on the leachate. At higher temperatures (40°C and 45°C), the germination on leached ash was significantly lower than on distilled water and the

Table 3.2. Scheffe's multiple comparisons of the average percent germination for each substrate, at each temperature regime, for seedlots A and B combined [7].

Temperature (°C)	Substrate			
	Distilled Wa[illegible]	Leachate	Leached Ash	Fresh Ash
45	30.0a	[illegible]4a	[illegible]7a	0.8a
40	35.2a	15.6a	3.8a	2.9a
35	84.4b	67.3b	52.9b	28.5b
30	78.3b	72.1b	57.7b	35.8c

[7] Comparisons were made on each column independently. Values followed by similiar letters were not significantly different at $p<0.05$.

Table 3.3. Scheffe's multiple comparisons of the average percent germination for each temperature regime, at each substrate, for seedlots A and B combined [8].

Substrate	Temperature Regime (°C)			
	30	35	40	45
Fresh Ash	35.8a	28.5a	2.9a	0.8a
Leached Ash	57.7b	52.9b	3.8a	2.7ab
Leachate	72.1bc	67.3bc	15.6b	14.4bc
Dist. Water	78.3c	84.4c	35.2c	30.0c

[8] Comparisons were made on each column independently. Values followed by similiar letters were not significantly different at $p<0.05$.

leachate but not on fresh ash (Table 3.3).

3.3.2. Germination Rate (R_{50} Values)

Overall, the main effects of temperature and substrate accounted for the results for the number of days to 50 percent germination (R_{50} Value) at $p=0.00000$ and $p=0.00075$ respectively (Table 3.4). The effect of these main factors was largely due to the germination response on fresh and leached ash in the 45°C regime. There was a significant interaction effect of temperature and substrate ($p=0.00011$, Table 3.4). Generally as temperature increased, the number of days to fifty percent germination (R_{50} Value) increased, but only significantly when compared to the 45°C temperature regime (Fig. 3.2). The R_{50} Value decreased (but not significantly) for the control medium (distilled water) between the 30°C and 35°C temperature regimes. All other comparisons were not significant (Tables 3.5 and 3.6).

3.3.3. Chemical Analyses of Burned Litter Residues

Chemical analyses of the soluble component of the seedbed media are summarized in Table 3.7 (leached ash solution; leachate; and fresh ash solution). The pH and the specific conductance of the leached ash were lower than those of the leachate and fresh ash solutions. The pH of the leachate was the highest, and the specific conductance of the fresh ash solution was the highest.

Table 3.4. Summary ANOVA for R_{50} values for germination data.

Part of Model	F-Ratio	DF	Prob.
Grand Mean	741.74	1.0	0.00000
Seedlot	0.82	1.0	0.36691
Temperature	22.85	3.0	0.00000
Substrate	5.92	3.0	0.00075
Seedlot*Temperature	0.10	3.0	0.95822
Seedlot*Substrate	1.08	3.0	0.36113
Temp*Substrate	4.06	9.0	0.00011
Seedlot*Temp*Substrate	0.67	9.0	0.73266

Note: The 48°C treatment was not included in the analysis.

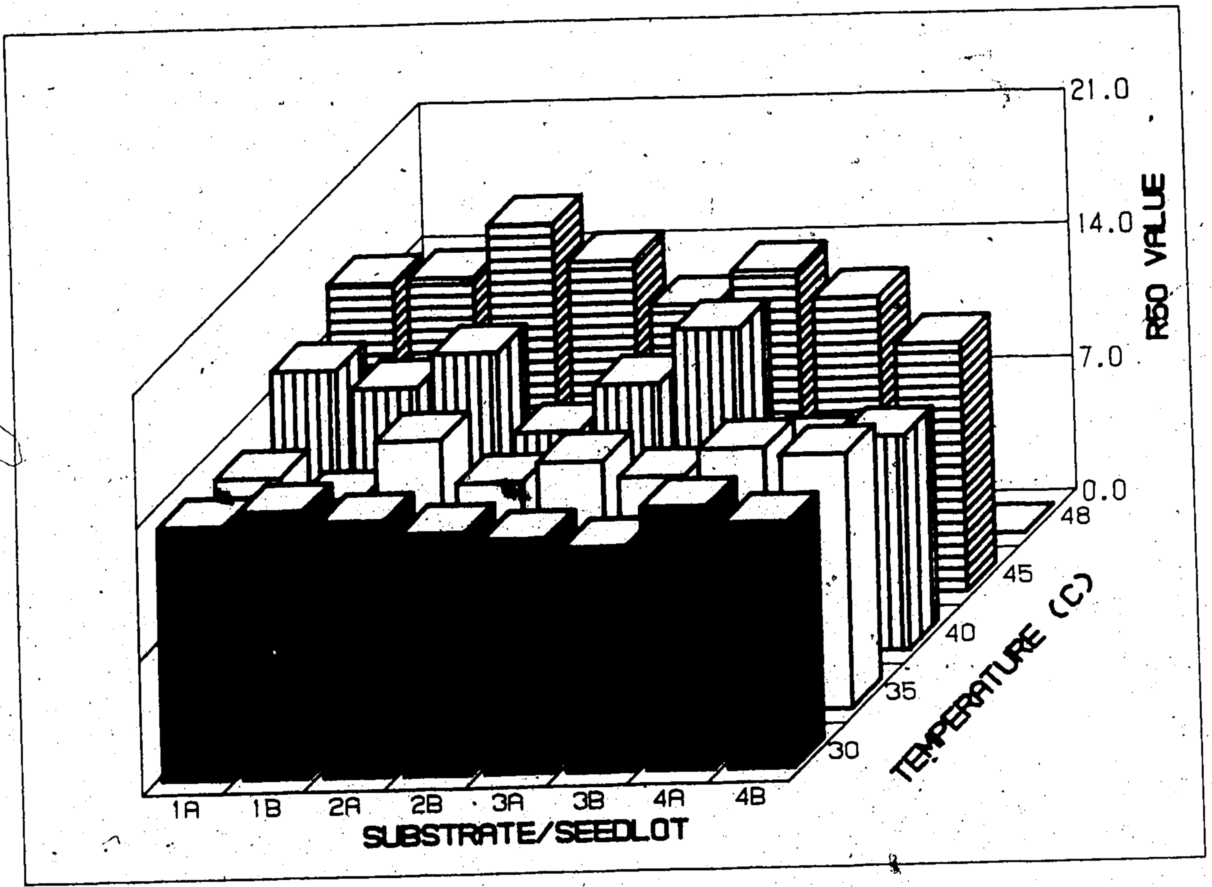


Fig. 3.2. R_{50} Values for seedlots A and B, for four substrates (1=distilled water, 2=leachate, 3=leached ash, and 4=fresh ash), subjected to five temperature regimes (30° C, 35°C, 40°C, 45°C, 48°C).

Table 3.5. Mean R_{50} values for each substrate at each temperature regime, for seedlots A and B combined, by Scheffe's multiple comparisons [9].

Temperature (°C)	Distilled Water	Leachate	Leached Ash	Fresh Ash
45	16.9a	18.7a	16.1a	14.3a*
40	14.8a	13.9a	15.6a	11.0b
35	12.1a	13.4a	12.8a	13.5b
30	13.1a	13.0a	12.0a	12.9b

[9] Comparisons were made on each column independently. Values followed by similiar letters were not significantly different at $p<0.05$.

*Note: only 4 seeds germinated in the fresh ash at 45°C.

APPENDIX I

Soil Profile Descriptions

Subgroup Classification: Orthic Gray Luvisol

Soil Profile No. 1: (East Side)

Horizon	Depth (cm)	Description
Burned OM	0-5	Black (10YR2/1d); burned organic matter, ash; abundant, fine and medium roots gradual wavy boundary; 2-7 cm thick.
Ae1	5-8	Dull yellowish brown (10YR5/6m), silt; structureless; loose; plentiful; fine and medium exped roots; gradual, wavy boundary; 0-4cm thick.
Ae2	8-20	Dull yellowish brown (10YR5/4m); silt; common, medium, faint, dull yellowish brown (10YR5/3) mottles; structureless; loose; few fine, vertical, exped roots; gradual wavy boundary; 10-14cm thick.
Bt	20+	Yellowish brown (10YR 5/6m); silty clay; few, fine, distinct, bright yellowish brown (10YR 6/8) mottles; strong, fine, granular; loose, few fine, random, exped roots; some stones.

Soil Profile No. 2: (West Side)

Burned OM	0-8	Black (10YR2/1d); burned organic matter and silt; structureless; loose; plentiful, fine, random, exped roots; gradual wavy boundary; 5-10cm thick.
Ae	8-19	Dull yellowish brown (10YR5/3m); silty; structureless; loose; plentiful, fine, random, exped roots; diffuse, wavy boundary; 8-12cm thick.
Bt	19+	Brown (10YR4/6m); silty clay, strong, fine granular; friable; very few, fine, random exped roots; some stones.

APPENDIX II

Summary ANOVA Tables of Microclimate Analyses

Analysis of Variance of Maximum Temperatures For All Weeks, With All Days Included

Part of Model	F-Ratio	DF	Prob	Epsilon
Micro	29.91	4.0	0.00002	
Error Term: Rep(Micro)				
Type	2.90	1.0	0.11936	
Micro*Type	4.44	4.0	0.02541	
Error Term: Type*Rep(Micro)				
Week	131.05	12.0	0.00000	
Greenhouse-Geisser Adj.	131.05	3.7	0.00000	0.31
Micro*Week	2.02	48.0	0.00108	
Greenhouse-Geisser Adj	2.02	14.8	0.04140	0.31
Error Term: Week*Rep(Micro)				
Type*Week	4.13	12.0	0.00003	
Greenhouse-Geisser Adj	4.13	3.7	0.00957	0.31
Micro*Type*Week	1.22	48.0	0.20205	
Greenhouse-Geisser Adj	1.22	14.7	0.30938	0.31
Error Term: Type*Week*Rep(Micro)				

Note: Type: Air and soil; Microsites: LO, LS, HO, HS, and MOSc.

Analysis of Variance of Maximum Temperatures, On Days Not Completely Covered With Clouds

Part of Model	F-Ratio	DF	Prob	Epsilon
Micro	32.68	4.0	0.00001	
Error Term: Rep(Micro)				
Type	3.81	1.0	0.07966	
Micro*Type	4.87	4.0	0.01932	
Error Term: Type*Rep(Micro)				
Week	158.93	12.0	0.00000	
Greenhouse-Geisser Adj.	158.93	3.9	0.00000	0.33
Micro*Week	2.25	48.0	0.00020	
Greenhouse-Geisser Adj	2.25	15.7	0.02029	0.33
Error Term: Week*Rep(Micro)				
Type*Week	5.58	12.0	0.00000	
Greenhouse-Geisser Adj	5.58	4.3	0.00094	0.36
Micro*Type*Week	1.12	48.0	0.31373	
Greenhouse-Geisser Adj	1.12	17.4	0.37326	0.36
Error Term: Type*Week*Rep(Micro)				

Note: Type: Air and soil; Microsites: LO, LS, HO, HS, and MOSc.

Analysis of Variance of Average Temperatures For All Weeks, With All Days Included

Part of Model	F-Ratio	DF	Prob	Epsilon
Micro	7.90	4.0	0.00385	
Error Term: Rep(Micro)				
Type	6.43	1.0	0.02957	
Micro*Type	0.53	4.0	0.71879	
Error Term: Type*Rep(Micro)				
Week	776.30	12.0	0.00000	
Greenhouse-Geisser Adj.	776.30	4.0	0.00000	0.34
Micro*Week	2.28	48.0	0.00016	
Greenhouse-Geisser Adj	2.28	16.2	0.01701	0.34
Error Term: Week*Rep(Micro)				
Type*Week	7.81	12.0	0.00000	
Greenhouse-Geisser Adj	7.81	3.8	0.00018	0.32
Micro*Type*Week	1.80	48.0	0.00647	
Greenhouse-Geisser Adj	1.80	15.2	0.077716	0.32
Error Term: Type*Week*Rep(Micro)				

Note: Type: Air and soil; Microsites: LO, LS, HO, HS, and MOSc.

Analysis of Variance of Average Temperatures, On Days Not Completely Covered With Clouds

Part of Model	F-Ratio	DF	Prob	Epsilon
Micro	8.11	4.0	0.00350	
Error Term: Rep(Micro)				
Type	5.65	1.0	0.03876	
Micro*Type	0.58	4.0	0.68113	
Error Term: Type*Rep(Micro)				
Week	777.28	12.0	0.00000	
Greenhouse-Geisser Adj.	777.28	4.3	0.00000	0.36
Micro*Week	2.68	48.0	0.00000	
Greenhouse-Geisser Adj	2.68	17.2	0.00443	0.36
Error Term: Week*Rep(Micro)				
Type*Week	8.95	12.0	0.00000	
Greenhouse-Geisser Adj	8.95	4.9	0.00000	0.41
Micro*Type*Week	1.69	48.0	0.01337	
Greenhouse-Geisser Adj	1.69	19.8	0.07446	0.41
Error Term: Type*Week*Rep(Micro)				

Note: Type: Air and soil; Microsites: LO, LS, HO, HS, and MOSc.

Analysis of Variance of Minimum Temperatures For All Weeks, With All Days Included

Part of Model	F-Ratio	DF	Prob	Epsilon
Micro	1.50	4.0	0.27319	
Error Term: Rep(Micro)				
Type	51.68	1.0	0.00003	
Micro*Type	1.17	4.0	0.38073	
Error Term: Type*Rep(Micro)				
Week	398.25	12.0	0.00000	
Greenhouse-Geisser Adj.	398.25	4.0	0.00000	0.33
Micro*Week	1.42	48.0	0.06533	
Greenhouse-[illegible]er Adj	1.42	15.9	0.18261	0.33
Error Term: We[illegible]*Rep(Micro)				
Type*Week	5.83	12.0	0.00000	
Greenhouse-Geisser Adj	5.83	3.8	0.00125	0.32
Micro*Type*Week	1.90	48.0	0.00325	
Greenhouse-Geisser Adj	1.90	15.3	0.05890	0.32
Error Term: Type*Week*Rep(Micro)				

Note: Type: Air and soil; Microsites: LO, LS, HO, HS, and MOSc.

Analysis of Variance of Minimum Temperatures, On Days Not Completely Covered With Clouds

Part of Model	F-Ratio	DF	Prob	Epsilon
Micro	1.61	4.0	0.24567	
Error Term: Rep(Micro)				
Type	50.63	1.0	0.00003	
Micro*Type	1.25	4.0	0.35041	
Error Term: Type*Rep(Micro)				
Week	455.19	12.0	0.00000	
Greenhouse-Geisser Adj.	455.19	4.0	0.00000	0.28
Micro*Week	1.56	48.0	0.02663	
Greenhouse-Geisser Adj	1.56	15.8	0.12659	0.28
Error Term: Week*Rep(Micro)				
Type*Week	4.80	12.0	0.00000	
Greenhouse-Geisser Adj	4.80	5.5	0.00086	0.46
Micro*Type*Week	1.58	48.0	0.02739	
Greenhouse-Geisser Adj	1.58	22.1	0.09302	0.46
Error Term: Type*Week*Rep(Micro)				

Note: Type: Air and soil; Microsites: LO, LS, HO, HS, and MOSc.

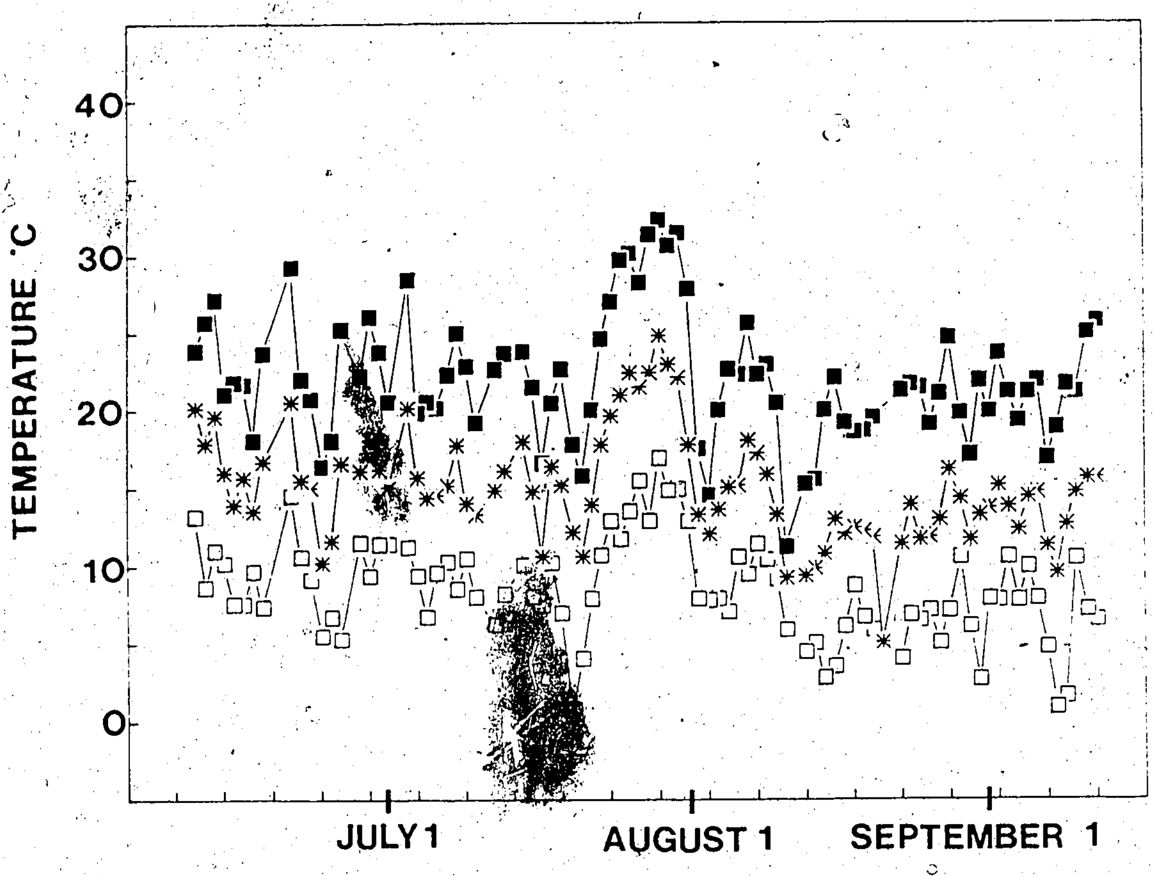
APPENDIX III

Duncan's Multiple Comparison Of Microsite Types For Weekly Maximum Temperatures, Air And Soil Combined.

	MICROSITE TYPE				
WEEK	LO	LS	HO	HS	MOSC
1	LS HS	LO HO MOSC	LS HS MOSC	LO HO MOSC	LS HO HS
2	LS HS	LO HO MOSC	LS HS MOSC	LO HO MOSC	LS HO HS
3	LS HS	LO HO MOSC	LS HS MOSC	LO HO MOSC	LS HO HS
4	LS HS	LO HO MOSC	LS HS MOSC	LO HO MOSC	LS HO HS
5	LS HS	LO HO MOSC	LS HS MOSC	LO HO MOSC	LS HO HS
6	LS HS	LO HO MOSC	LS HS	LO HO MOSC	LS HS
7	LS HS	LO HO MOSC	LS HS MOSC	LO HO MOSC	LS HO HS
8	LS HS	LO HO MOSC	LS HS	LO HO MOSC	LS HS
9	LS HS	LO HO MOSC	LS HS	LO HO MOSC	LS HS
10	LS HS	LO HO MOSC	LS HS	LO HO MOSC	LS HS
11	LS HS	LO HO MOSC	LS HS	LO HO MOSC	LS HS
12	LS HS	LO HO MOSC	LS HS MOSC	LO HO MOSC	LS HO HS
13	HS HO	HO	LS HS MOSC LO	LO HO MOSC	HO HS

Note: Microsite types listed for each week significantly different from each other at the $p < 0.05$ level. For microsite comparisons not listed, these were not significantly different at $p < 0.05$ level.

APPENDIX IV



Daily Average (✱), Maximum (■), and Minimum (□) Temperatures For Stevenson Screen Monitor.

APPENDIX V

Linear Regression Analyses of Microsite Types

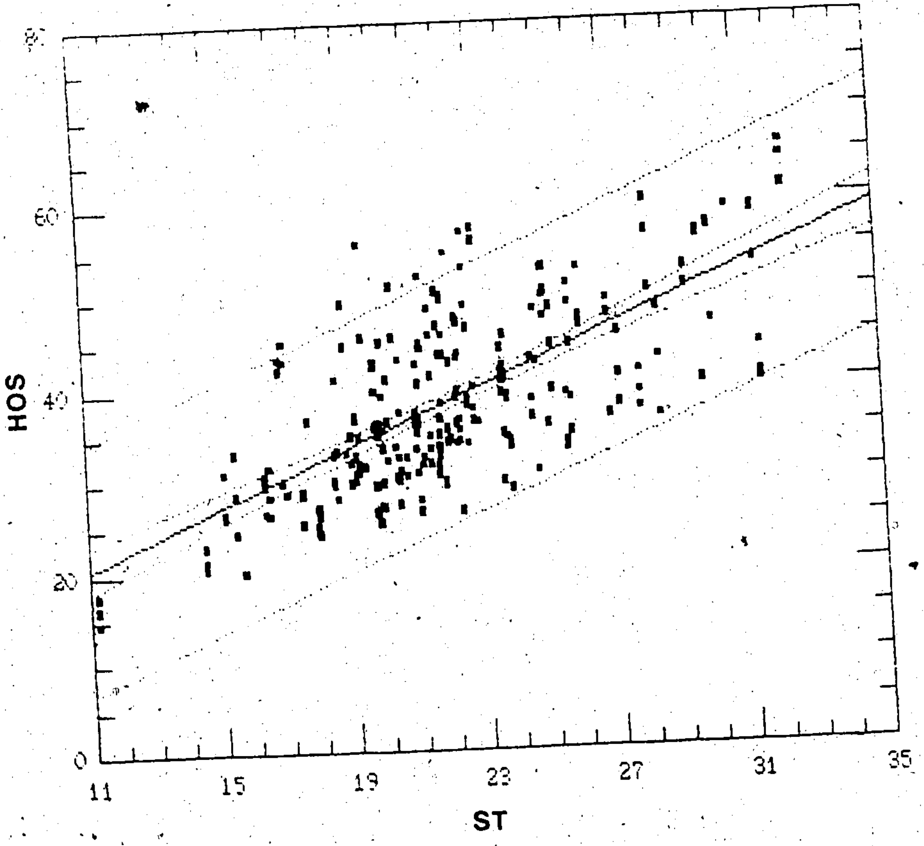
Summary Table

Comparison of Microsite Maximum Temperatures to Stevenson Screen Maximum Temperatures (in Descending Order of R-Level of Significance).

Microtype	r	Stnd.Err. of Est.	Equation	Predicted Temp. for STMAX=30°C
1. MOScA	.87	2.97	MOScA = 4.08349 + 1.31904(STMAX)	43.65
2. HSA	.87	2.44	HSA = 2.01386 + 1.07165(STMAX)	34.16
3. LSA	.87	2.55	LSA = 4.01385 + 1.10495(STMAX)	37.09
4. HOA	.86	3.43	HOA = 2.71639 + 1.41781(STMAX)	45.25
5. LOA	.85	3.52	LOA = 5.30370 + 1.38132(STMAX)	46.74
6. LSS	.78	2.81	LSS = 4.51232 + 0.86657(STMAX)	30.51
7. MOScS	.77	4.22	MOScS = 2.911 + 1.28051(STMAX)	41.33
8. LOS	.76	4.85	LOS = 1.88466 + 1.35932(STMAX)	42.66
9. HSS	.73	3.82	HSS = 2.34172 + 1.00684(STMAX)	32.55
10. HOS	.69	6.87	HOS = 3.10374 + 1.60137(STMAX)	51.14

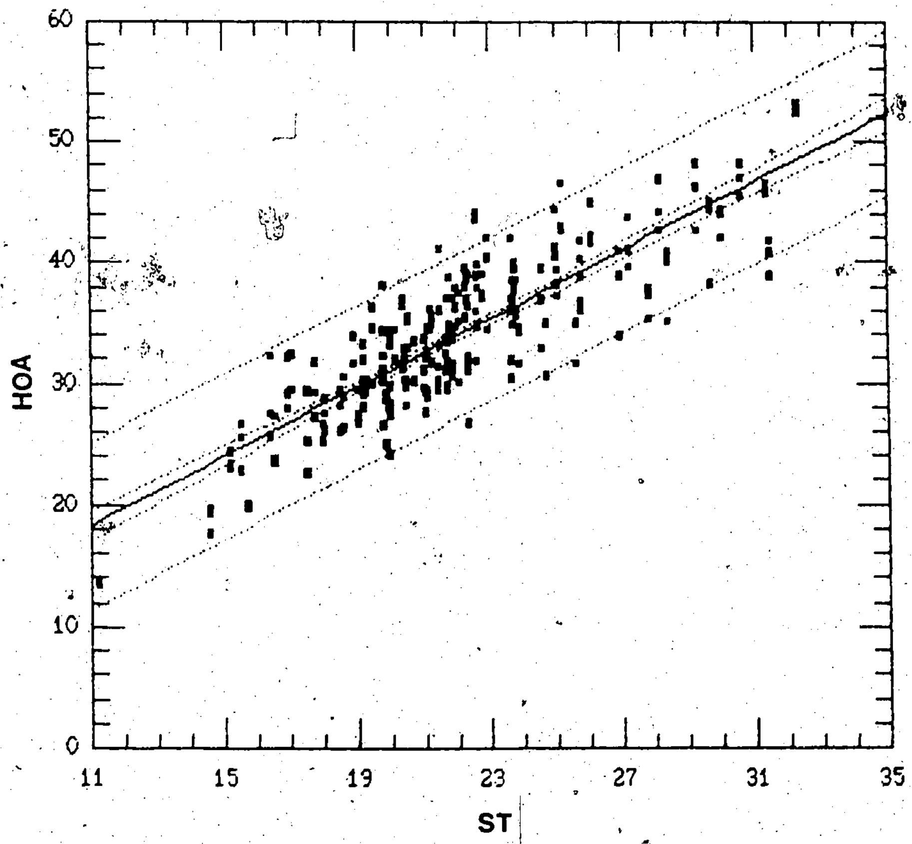
Note: A after the microsite type denotes air temperature reading. S denotes soil temperature reading.

```
Regression of High Albedo, Open, Soil (HOS) Maximum Temperatures on
              Stevenson Screen (ST) Maximum Temperatures

Dependent variable: HOS
Independent variable: ST

Parameter    Estimate   Standard       T         Prob.
                          Error      Value       Level
---------------------------------------------------------
Intercept    3.10374    2.45334     1.2651     0.20706
Slope        1.60137    0.10921    14.6636     0.00000
---------------------------------------------------------

                      Analysis of Variance
---------------------------------------------------------------------
Source            Sum of Squares    Df  Mean Square  F-Ratio  Prob. Level
Model                 10140.039      1   10140.039   215.021    0.00000
Error                 11318.005    240      47.158
---------------------------------------------------------------------
Total (Corr.)         21458.044    241

Correlation Coefficient = 0.687424
R-squared = 47.26 percent
Stnd. Error of Est. = 6.86719
```

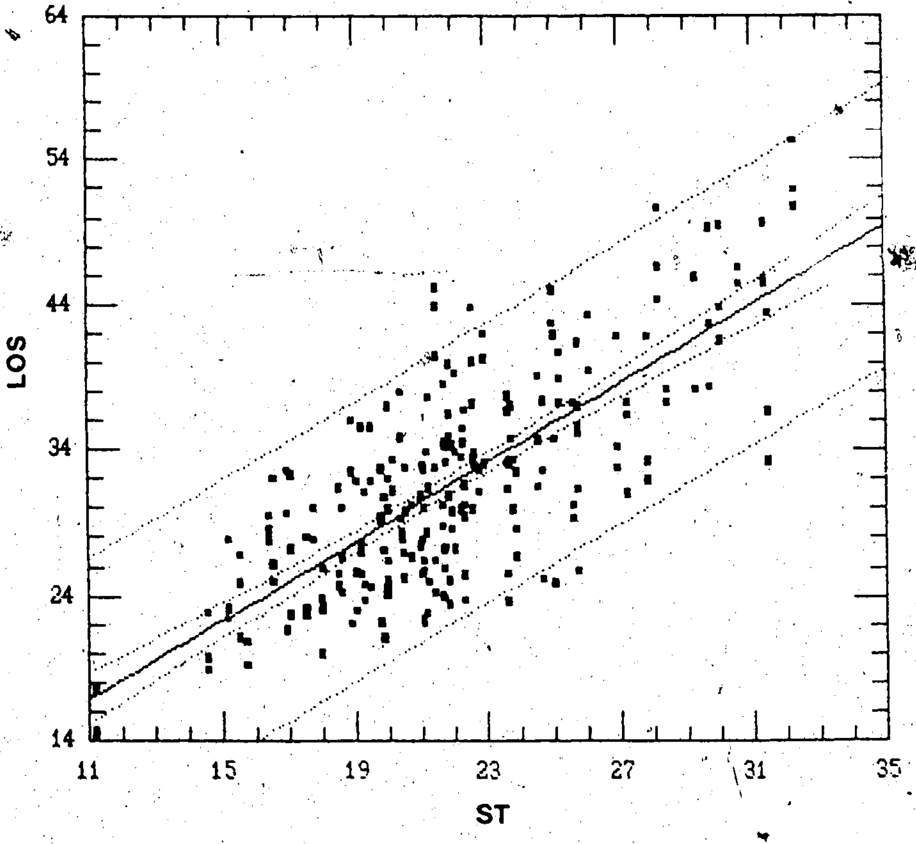


Regression of High Albedo, Open, Air (HOA) Maximum Temperatures on Stevenson Screen (ST) Maximum Temperatures

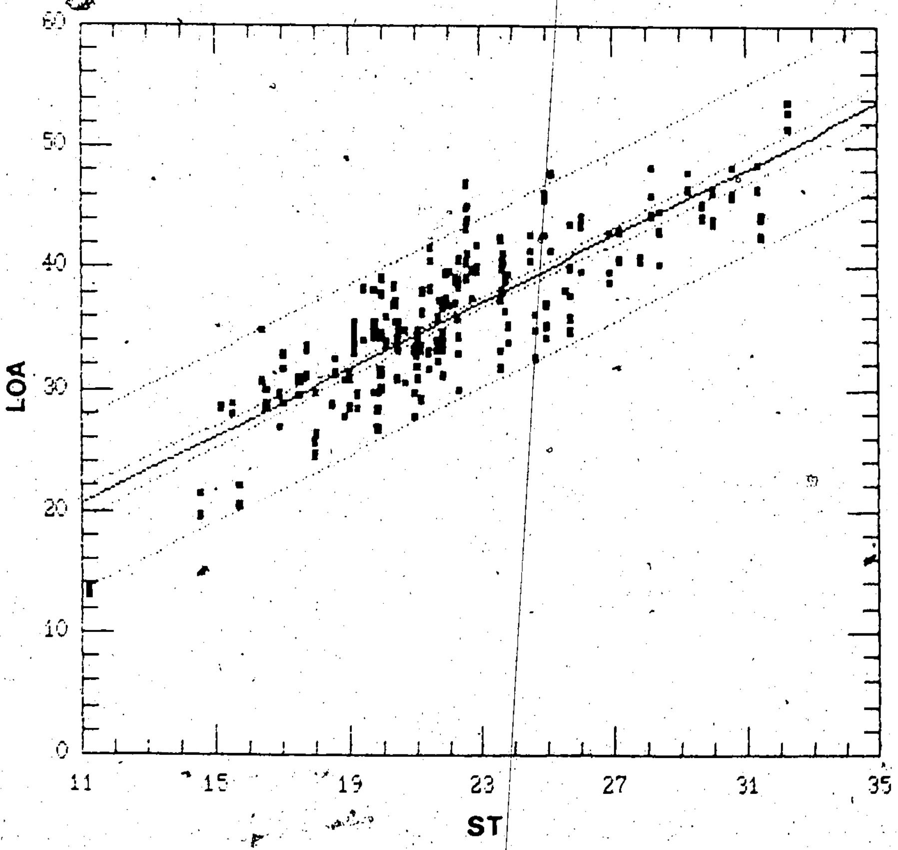
```
Dependent variable: HOA
Independent variable: ST

Parameter   Estimate   Standard      T          Prob.
                       Error       Value        Level
-------------------------------------------------------------------------
Intercept   2.71639    1.18250    2.2972       0.02243
Slope       1.41781    0.05274   26.8821       0.00000
-------------------------------------------------------------------------

                    Analysis of Variance
-------------------------------------------------------------------------
Source            Sum of Squares   Df  Mean Square   F-Ratio  Prob. Level
Model                8514.5212      1   8514.5212   722.6481    0.00000
Error                2980.9444    253     11.7824
-------------------------------------------------------------------------
Total (Corr.)       11495.466     254

Correlation Coefficient = 0.860631
R-squared = 74.07 percent
Stnd. Error of Est. = 3.43255
```



```
Regression of Low Albedo, Open, Soil (LOS) Maximum Temperatures on
              Stevenson Screen (ST) Maximum Temperatures

Dependent variable: LOS
Independent variable: ST

Parameter    Estimate   Standard      T         Prob.
                         Error      Value       Level
-------------------------------------------------------------------
Intercept    1.88466    1.71935    1.09614     0.27416
Slope        1.35932    0.07669   17.72380     0.00000
-------------------------------------------------------------------

                        Analysis of Variance
-------------------------------------------------------------------
Source          Sum of Squares   Df  Mean Square  F-Ratio  Prob. Level
Model                7392.4331    1    7392.4331  314.134    0.00000
Error                5436.0493  231      23.5327
-------------------------------------------------------------------
Total (Corr.)        12828.482  232

Correlation Coefficient = 0.75911
R-squared = 57.63 percent
Stnd. Error of Est. = 4.85105
```

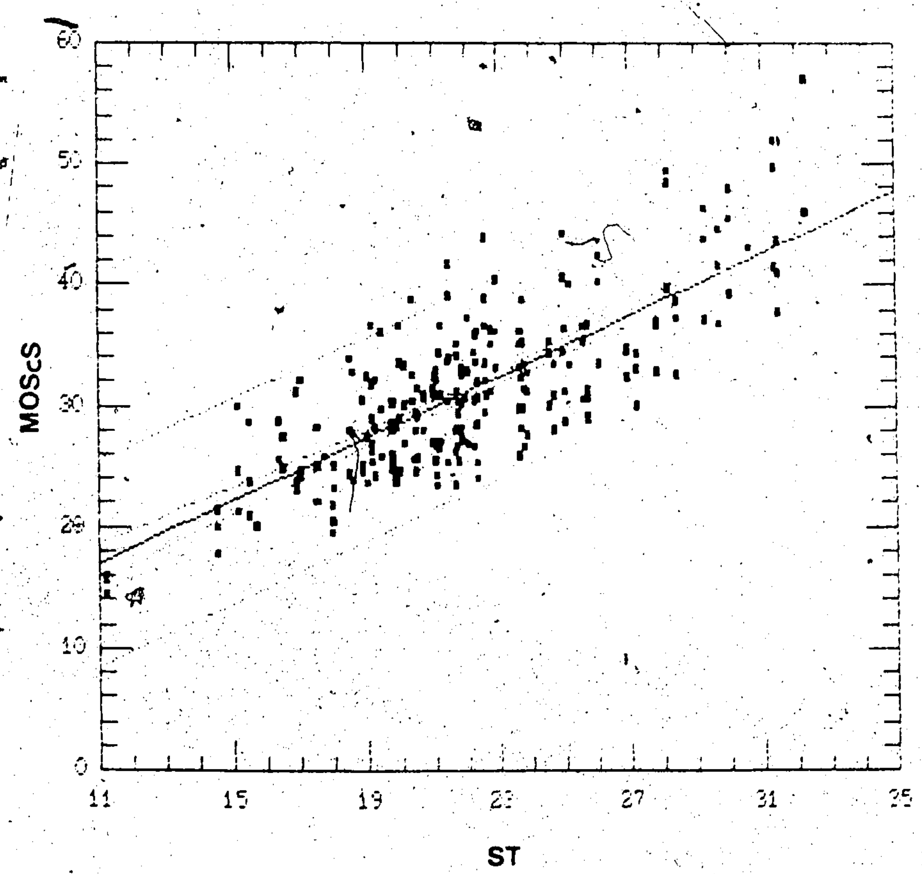


```
      Regression of Low Albedo, Open, Air (LOA) Maximum Temperatures on
                Stevenson Screen (ST) Maximum Temperatures

Dependent variable: LOA
Independent variable: ST

Parameter    Estimate  Standard      T        Prob.
                        Error      Value      Level
-----------------------------------------------------------------
Intercept    5.30370   1.26642    4.18794    0.00000
Slope        1.38132   0.05619   24.58360    0.00000
-----------------------------------------------------------------

                      Analysis of Variance
-----------------------------------------------------------------
Source          Sum of Squares   Df  Mean Square   F-Ratio   Prob. Level
Model               7493.7852     1    7493.7852   604.3524   0.00000
Error               2839.5302   229      12.3997
-----------------------------------------------------------------
Total (Corr.)      10333.315    230

Correlation Coefficient = 0.85159
R-squared = 72.52 percent
Stnd. Error of Est. = 3.52132
```



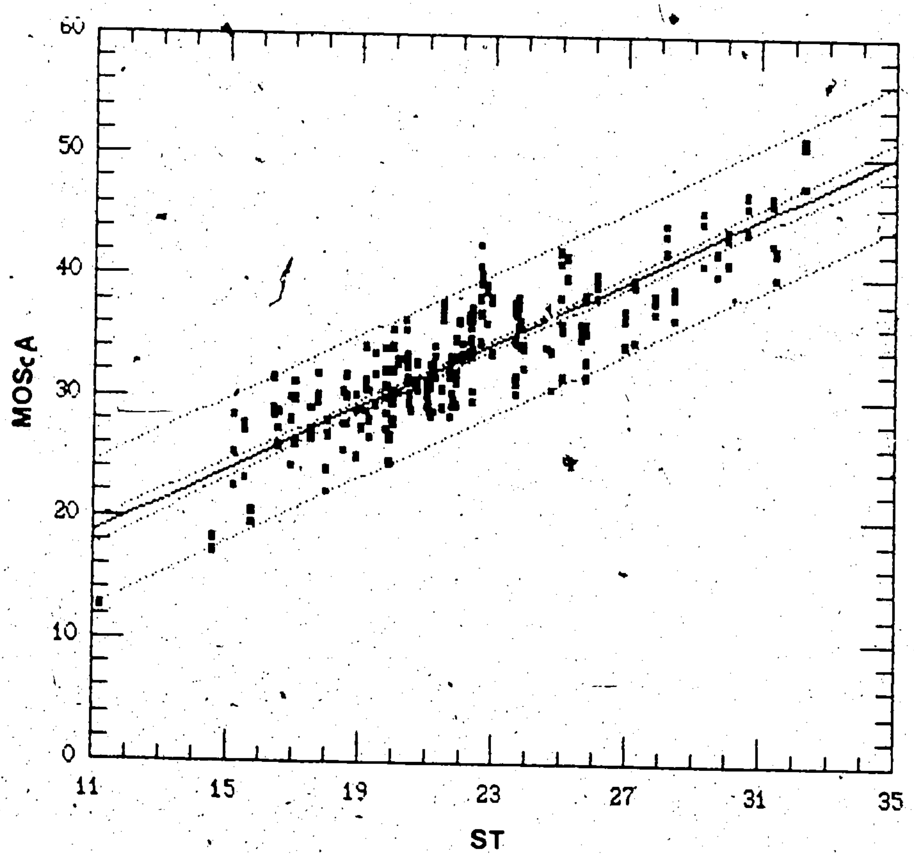
Regression of Medium Albedo, Open, Soil (MOScS) Maximum Temperatures on Stevenson Screen (ST) Maximum Temperatures

```
Dependent variable: MOScS
Independent variable: ST

Parameter      Estimate   Standard      T         Prob.
                          Error       Value       Level
---------------------------------------------------------------
Intercept      2.911      1.52688     1.9065      0.05779
Slope          1.281      0.06815    18.7883      0.00000
---------------------------------------------------------------

                      Analysis of Variance
---------------------------------------------------------------------
Source          Sum of Squares   Df  Mean Square   F-Ratio   Prob. Level
Model              6297.2446      1    6297.2446   353.0014  0.00000
Error              4245.7172    238      17.8391
---------------------------------------------------------------------
Total (Corr.)     10542.962     239

Correlation Coefficient = 0.772848
R-squared = 59.73 percent
Stnd. Error of Est. = 4.22364
```

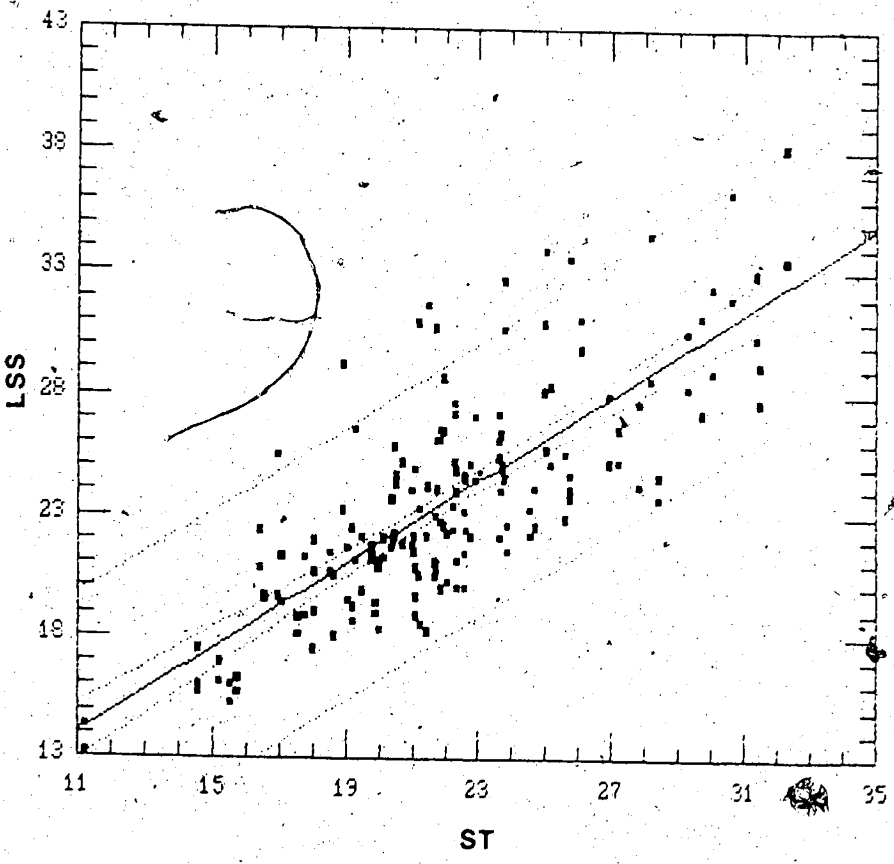


Regression of Medium Albedo, Open, Air (MOScA) Maximum Temperatures on Stevenson Screen (ST) Maximum Temperatures

```
Dependent variable: MOScA
Independent variable: ST

Parameter    Estimate     Standard       T          Prob.
                           Error       Value        Level
---------------------------------------------------------------------
Intercept    4.08349      1.02148     3.9976       0.00000
Slope        1.31904      0.04556    28.9518       0.00000
---------------------------------------------------------------------

                        Analysis of Variance
---------------------------------------------------------------------
Source             Sum of Squares   Df  Mean Square  F-Ratio   Prob. Level
Model                 7369.5874      1    7369.5874  838.2059  0.00000
Error                 2224.4004    253       8.7921
---------------------------------------------------------------------
Total (Corr.)         9593.9877    254

Correlation Coefficient = 0.87644
R-squared = 76.81 percent
Stnd. Error of Est. = 2.96515
```

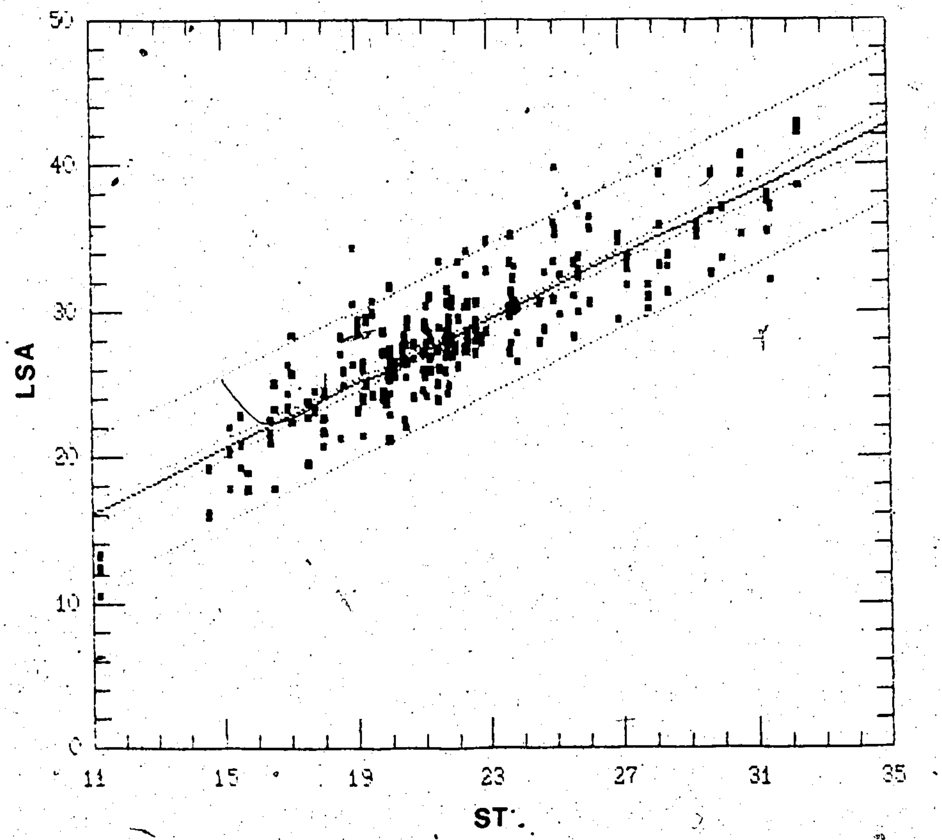


```
     Regression of Low Albedo, Shaded, Soil (LSS) Maximum Temperatures
               on Stevenson Screen (ST) Maximum Temperatures

Dependent variable: LSS
Independent variable: ST

Parameter    Estimate      Standard       T          Prob.
                            Error        Value       Level
-------------------------------------------------------------------
Intercept    4.51232       1.16382      3.8772       0.00001
Slope        0.86657       0.05208     16.6393       0.00000
-------------------------------------------------------------------

                        Analysis of Variance

Source           Sum of Squares    Df  Mean Square   F-Ratio    Prob. Level
Model                2181.9207      1    2181.9207   276.8666   0.00000
Error                1379.1341    175       7.8808
---------------------------------------------------------------------------
Total (Corr.)        3561.0548    176

Correlation Coefficient = 0.782763
R-squared = 61.27 percent
Stnd. Error of Est. = 2.80727
```

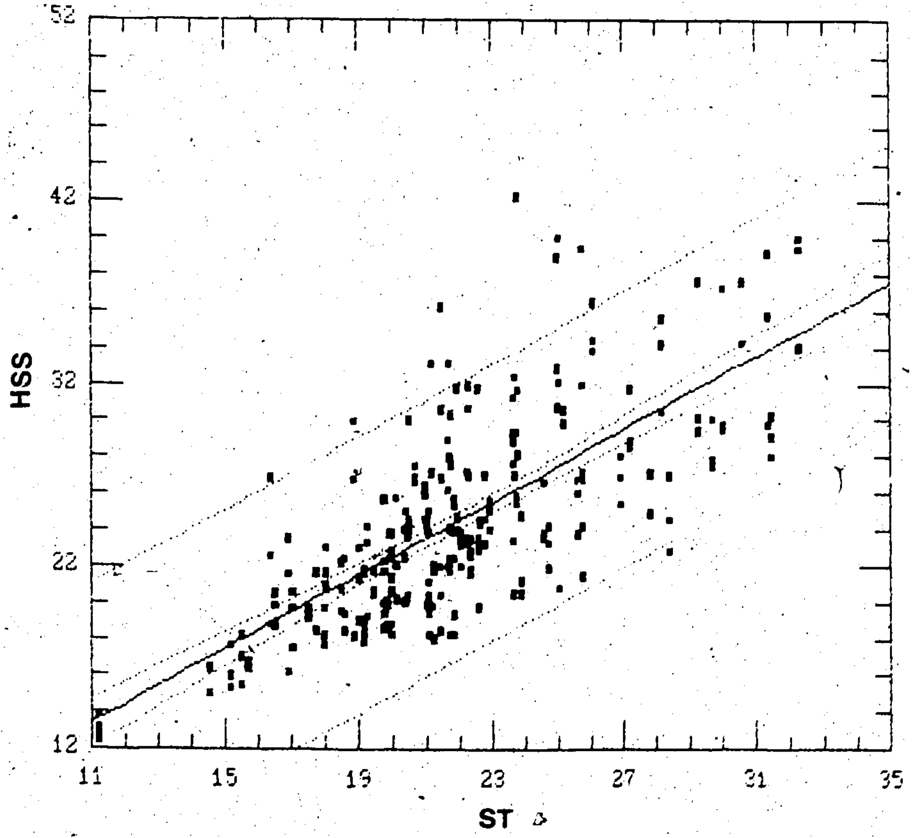


Regression of Low Albedo, Shaded, Air (LSA) Maximum Temperatures on Stevenson Screen (ST) Maximum Temperatures

```
Dependent variable: LSA
Independent variable: ST

Parameter    Estimate    Standard      T        Prob.
                          Error      Value      Level
---------------------------------------------------------------
Intercept    4.01385     0.88036    4.5593     0.00000
Slope        1.10495     0.03923   28.1675     0.00000
---------------------------------------------------------------
                     Analysis of Variance
---------------------------------------------------------------
Source         Sum of Squares   Df  Mean Square   F-Ratio    Prob. Level
Model              5155.0227     1    5155.0227   793.4099   0.00000
Error              1630.8224   251       6.4973
---------------------------------------------------------------
Total (Corr.)      6785.8450   252

Correlation Coefficient = 0.871592
R-squared = 75.97 percent
Stnd. Error of Est. = 2.54898
```

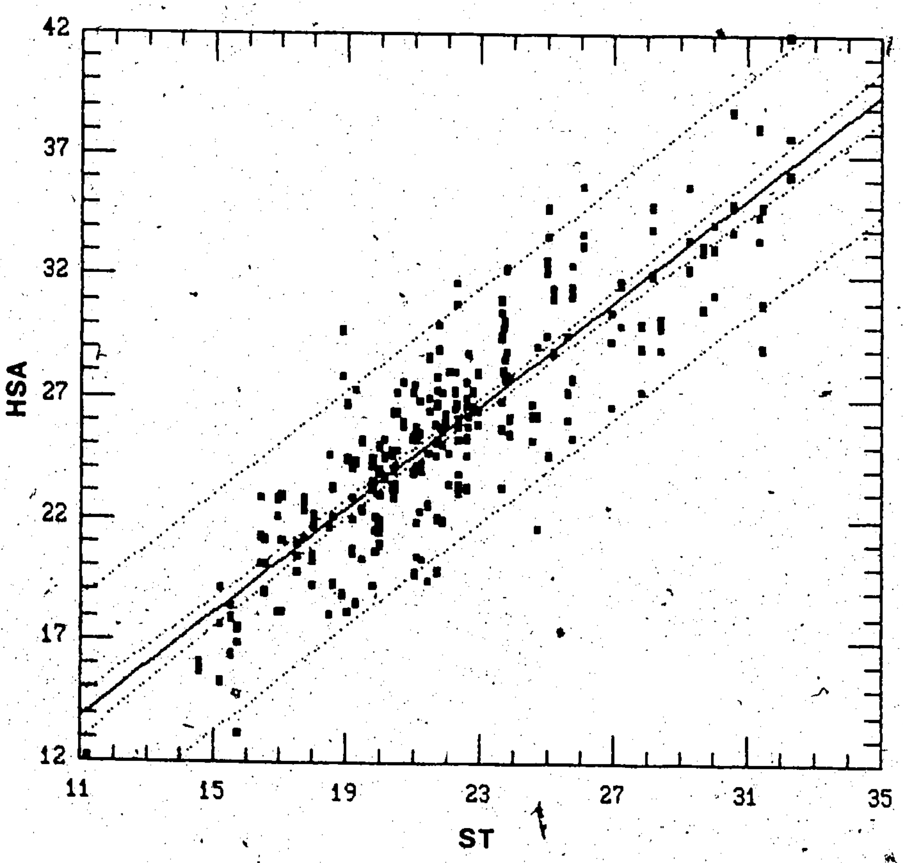


```
Regression of High Albedo, Shaded, Soil (HSS) Maximum Temperatures
          on Stevenson Screen (ST) Maximum Temperatures

Dependent variable: HSS
Independent variable: ST

Parameter    Estimate     Standard      T         Prob.
                           Error      Value       Level

Intercept    2.34172      1.34159     1.7455      0.08215
Slope        1.00684      0.05979    16.8372      0.00000

                       Analysis of Variance

Source          Sum of Squares   Df  Mean Square  F-Ratio   Prob. Level
Model              4139.5233      1   4139.5233   283.4926  0.00000
Error              3577.4586    245     14.6019

Total (Corr.)      7716.9819    246

Correlation Coefficient = 0.732405
R-squared = 53.64 percent
Stnd. Error of Est. = 3.82124
```



Regression of High Albedo, Shaded, Air (HSA) Maximum Temperatures
on Stevenson Screen (ST) Maximum Temperatures

```
Dependent variable: HSA
Independent variable: ST

Parameter      Estimate     Standard      T          Prob.
                             Error       Value       Level
-------------------------------------------------------------------------
Intercept      2.01386      0.852838   2.3614      0.01897
Slope          1.07165      0.037982  28.2147      0.00000
-------------------------------------------------------------------------

                          Analysis of Variance
-------------------------------------------------------------------------
Source              Sum of Squares    Df  Mean Square   F-Ratio   Prob. Level
Model                   4729.2798      1    4729.2798   796.0679  0.00000
Error                   1497.0815    252       5.9408
-------------------------------------------------------------------------
Total (Corr.)           6226.3613    253

Correlation Coefficient = 0.871526
R-squared = 75.96 percent
Stnd. Error of Est. = 2.43738
```



APPENDIX VI

Summary of Results From Pilot Laboratory Studies

The following changes were made to the experimental design due to results from a series of pilot studies:

1. Stratified seed only was used, rather than both unstratified and stratified seed. This was done because stratified seed response was more representative of field conditions. Unstratified seed responses in pilot tests did not illuminate new questions, or answer old ones.

2. Constant maximums were maintained for 2 hours, instead of for 4 hours, for all growth rooms. Pilot germination experiments were conducted with maximum temperatures established for 4 hours. Results were poor in these pilot studies, and therefore duration of the extremes was reduced. Due to instrumentation limitations, more daily fluctuation was not possible despite better rationalization. The growth rooms were limited to only 2 temperature variations, and were unable to carry out a regime such as: 8 hours at 20 C in darkness, RH=95%; 4 hours at 20 C in light, RH=95%; 3 hours at 30 C with light, RH=95%; 1 hours at 35 C with light, RH=95%; 4 hours at 30 C, with light, Rh=95%; and 4 hours at 20 C in light RH=95%. Availability of computerized growth rooms would eliminate this problem.

3. Photoperiod was maintained for 16 hours rather than the 8 hours specified by International Seed Testing Association (1985) (ISTA) rules. Pilot studies closely adhered to standard ISTA conditions; however a closer approximation to the average summer day length for the final experiment was more appropriate, given the overall objective of the study. and local climatic conditions.

4. Two seed sources were used, from approximately the same latitude. This was done to increase confidence ~~in~~ observed seed responses to treatment levels. Results from some of the pilot studies were so low even in standard ISTA (1985) conditions on filter paper, that the original seedlot was suspected of having low viability.

5. The amount of leached ash that was used was equivalent to the weight of unleached (fresh) ash, minus the weight lost during leaching. Original pilot experiments used equivalent amounts of leached ash (1.5g) as unleached (fresh) ash (1.5g). By doing this, the pilot studies failed to discern any difference between the chemical and physical effects of the ash.

6. Kimpak, a multilayered absorbent material, was used rather than two filter papers (Whatman no. 2) with all substrates tested. The purpose was to eliminate moisture stress. Pilot studies using filter paper in petri dishes were unexpected failures, even at standard ISTA temperatures with distilled water. The fast rate of evaporation on filter paper was enough to inhibit germination without the effect of either temperature or substrate. When filter papers were used with ash, a carbonate-like stone formed, and remained for the duration of the experiment despite the addition of moisture. Evaporation tests revealed that rewetting of the filter paper resulted in faster initial rates of evaporation. The advantage of Kimpak was that it was able to maintain a comparatively larger volume of water for a longer period of time (more than 24 hours, even at extreme temperatures). Since moisture stress was not intended to be the variable tested in this study, moisture deficits were eliminated with the use of Kimpak.

7. Prior to the final experiment, seeds were not x-rayed to determine viability. All seeds used in the pilot studies were x-rayed. Germination percent based on live seed for the final experiment (germination value), was considered of impractical value since 1) germination percentages were already given by Pine Ridge Nursery, 2) germination percentages from pilot studies under control conditions on Kimpak were similiar to Nursery results, and 3) forest managers conducting direct seeding projects are more concerned with actual germination response based on the seedlot used in field conditions than with germination value. Future laboratory provenance tests may be required to determine germination percentage based on live seed, established from factors of environmental conditioning from different site preparation treatments; however until the influence of environmental conditioning by site preparation types on seed germination is established, the cost of time and money to determine germination based on live seed is unjustified.

8. Six replicates of forty seeds determined the experimental unit. Strict adherence to standard ISTA conditions for pilot studies using four replicates of 100 seeds was unjustified. Pilot study attempts to increase sample size to five replicates with 100 seeds each, resulted in unnecessary wastage of seed. Since the number of petri dishes, (not the number of seeds per petri dish), established the number of experimental units, it was more appropriate statistically to increase the number of replicates for each treatment type rather than the number of seeds per petri dish.

9. Leached ash in the final experiment, was created by washing fresh ash with 25 ml of distilled water ten times.

In the pilot studies, washing was completed fourteen times. Washing (leaching) fourteen times was unnecessary because the extra four washings did not reduce the electrical conductivity by an appreciable amount, and only diluted the leachate concentrate. Also, a pilot study was conducted to test the influence of different concentrations of leachate on seed germination response. This study demonstrated that germination decreased as leachate concentration increased, and further confirmed results demonstrated by Woodard (1983 and 1987).

10. The experimental unit was petri dishes. Spencer Lemaire plastic boxes were not used to contain the petri dishes, because statistically this would confuse the experimental design. In addition, although the advantage of these boxes for standard germination experiments has been described by Wang and Ackerman (1983) for their ability to retain moisture, results from pilot studies indicated that the moisture holding properties of Kimpak were superior.

Literature Cited

International Seed Testing Association. 1985. International rules for seed testing 1985. Seed Sci. & Technol. 13:299-355.

Wang, B.S.P. and Ackerman, F. 1983. A new germination box for tree seed testing. Environ. Can. Can. For. Serv., PNFI. Info. Rep. PI-X-27.

Woodard, P.M. 1983. Germination success of _Pinus contorta_ Dougl. and _Picea engelmannii_ Parry on burned seedbeds. For. Ecol. Manage. 5:301-306.

Woodard, P.M. and G. Cummins. 1987. Engelmann spruce, lodgepole pine and subalpine fir seed germination success on ashbed conditions. Northwest Sci. 61:233-238.

APPENDIX VII

Seedlot Specifications

Source A

White Spruce Seedlot DL 72-21-4-83

Latitude:55°17′
Longititude: 113°05′
Elevation: 640 m
Collection date: August to September, 1983
Purity: 98.2%
1000 Seed Weight: 1.89 g
Germination: Untreated 77.5%
Stratified 84.2%
(germination 21 days at constant 25°C, 12 hour nights, 12 hour days)
Moisture Content: 6.0%
Storage Temperature: -18°C

Source B

White Spruce Seedlot DL 68-12-4-83 Sw

Latitude: 54°55′
Longitude: 112°
Collection date: August to September 1983
Purity: 98.5%
1000 Seed Weight: 2.171 g
Germination: Untreated 81.9% (June, 1986)
Stratified 89.3% (June, 1986)
(germination 21 days at constant 25°C, 12 hour nights, 12 hour days).
Moisture Content: 6.4%
Storage Temperature: -18°C