PRESCRIPTION FOR THE AERIAL ENVIRONMENT OF A PLASTIC GREENHOUSE NURSERY

D. F. W. Pollard and K. T. Logan[1]

ABSTRACT.-- Investigations into the aerial environment favoring rapid growth of tree seedlings in plastic greenhouses are described. Controllable factors studied were day and night temperatures, and high and low intensity extension of photoperiod; a confounding influence of carbon dioxide enrichment and high humidity was also examined. Experiments were designed within the limits of applicability of results to the greenhouse control system, and were made on three commercially important species: jack pine, black spruce, and white spruce. Recommendation, are given for each species, and also a single prescription is given for greenhouses containing all three specics. The merits of high and low intensity photoperiod supplements are discussed.

The idea of using controlled environments for rapid production of tree seedlings is not new, but only recently has the principle been applied to forest nurseries in Canada.

Development of controlled-environment nurseries in North America has been stimulated by a trend toward container-grown seedlings and increasing interest in mechanized production systems. Typically, controlled environment nurseries comprise plastic greenhouses with various systems of temperature and photoperiod control. Automatic watering is usually included and may incorporate a nutrient delivery system. More elaborate units include means for carbon dioxide enrichment of the atmosphere, humidity control, and high intensity light supplement. Forest tree seedling production is approaching the sophistication that has characterized commercial horticulture for many years.

Three important factors of environmental control systems are engineering feasibility, cost, and the plant's requirements. The first two are intimately related and readily assessed so usually dominate design of a unit. The plant's requirements, however, are often poorly understood. Despite several decades of research into tree growth, the nurseryman equipped with controlled

1 Petawawa Forest Experiment Station, Chalk River, Ontario, Canada

environments does-not have adequate information on the requirements of tree species, especially northern conifers.

This was the position of the Ontario Ministry of Natural Resources (OMNR) when they ventured into production of seedlings in controlled environments at Swastika, Ontario. Their objective was to produce two, and eventually three, batches of seedlings each year by extending the effective growing season and by accelerating growth during the first year. This paper is an account of a series of experiments that were conducted at the Canadian Forestry Service laboratories at Petawawa to prescribe the environments best suited to meet this objective.

The controlled environment facilities at the Swastika nursery consist of two plastic greenhouses (40 m long, 10 m wide, and 4 m high at center) fitted with raised platforms for pallets of containerized seedling trees. Main environmental control is for temperature, through heat exchangers in a plenum at the end of each greenhouse, and for photoperiod, through a series of overhead incandescent lamps providing night illumination of about 400 lux. Ventilators are used in hot weather. Atmospheric carbon dioxide can be increased by a propane burner, although the benefit is lost when ventilators are open. A central trough carries a motorized boom for spraying water and nutrient solutions. Each house holds about a million 5/8 inch tubelings.

The effects of day and night temperature, carbon dioxide enrichment, and photoperiod were tested on the three main species raised at Swastika--jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), and white spruce (*Picea glauca*) to determine the optimum aerial environment for the species.

METHODS

As far as possible, materials and cultural methods used in the Swastika nursery were duplicated in the controlled environment experiments. Seed of the three species was sown in 5/8-inch plastic tubes. In the first three experiments a fine-screened 3- to-1 mixture of peat and vermiculite was used; in subsequent experiments tubes were filled with peat muck as used by the nursery. A nutrient solution (Ingestad 1967) was applied daily (except in Experiment 1, where solution was applied three times a week)

Unless stated otherwise, experiments were conducted in small growth cabinets with illumination of 22,000 lux provided throughout a 16 h photoperiod. The duration of each experiment was 8 to 12 weeks from sowing. Treatment effects were assessed from ovendry weight (95°C) and heights attained over this period.

Experiment 1--Effect of Daytime Temperature

After germination, about 100 tubelings of each of the 3 species were placed in each of 5 cabinets. Temperatures in the cabinets were 15, 20, 25, 30, and 35 C, respectively, during the day and 15°C at night. The range of temperatures tested was restricted to the practical limits of greenhouse operation. The tubelings and treatments were rotated weekly through the five cabinets to eliminate the cabinet effects as a source of experimental error.

Twelve weeks after sowing, 15 seedlings were taken from each species for individual analysis of roots and shoots and height measurements (table 1). For both spruce species a 25 day temperature yielded tallest and heaviest seedlings. Jack pine growth did not peak in a single temperature regime but remained high over a daytime range of 25 to 35°C. Evidently daytime temperature is less critical in jack pine than in spruces.

Experiment 2--Effect of Nighttime Temperature

Experimental design was similar to Experiment 1. Four night temperatures were tested, 15, 20, 25, and 30 C with a daytime temperature of 30°C. Again, the test temperatures were based on practical limitations of greenhouse control at Swastika (table 2).

As in Experiment 1, temperature was most critical in spruce with both species achieving maximum height and weight with a night temperature of 20°C. Jack pine weight was unaffected by changes between 15 and 25°C, although height decreased slightly over this range.

The seedlings in Experiment 2 weighed approximately three times as much as the seedlings in Experiment 1. This is probably a result of differences in watering and feeding because the seedlings in Experiment 2 were given a daily top watering with nutrient solution that the Experiment 1 seedlings were not.

Experiment 3.--Effect of Carbon Dioxide Enrichment

Seedlings were raised as in Experiment 1 and subjected to either ambient or enriched CO2 concentration. For enrichment CO2 was bled into the growth cabinet from tanks of compressed gas and maintained at a concentration of between 1,010 and 1,150 ppm. The cabinet atmosphere was monitored continuously with an infra-red gas analyzer. Cabinets were maintained under a day/night regime of 30/15°C and 16 h photoperiod. The enriched cabinet was sealed to prevent excessive leakage of CO_2.

Results with jack pine in this experiment did not correspond to those obtained in previous work (table 3) (Yeatman 1970). Carbon dioxide enrichment apparently depressed shoot growth by about 11 percent although this was partly offset by a 40 percent increase in root growth. Root growth

Table 1.--Height and dry weight[1] of jack pine, white spruce, and black spruce grown for 12 weeks in day temperatures of 15 - 35°C and night temperatures of 15° C

Day temperature (C°)	Height	Dry weight: Shoot	Dry weight: Root	Dry weight: Seedling
JACK PINE				
	cm[2]	g	g	g
15	7.2a	0.096a	0.038a	0.134a
20	10.0b	.172b	.059c	.231b
25	12.0c	.215xc	.053bc	.268bc
30	12.5cd	.219c	.045ab	.255bc
35	12.8d	.238c	.050bc	.288c
WHITE SPRUCE				
15	4.3a	0.030a	0.007ab	0.037a
20	4.6a	.051b	.008bc	.059b
25	5.6b	.068c	.010c	.078c
30	4.5a	.048b	.007ab	.055ab
35	4.2a	.034ab	.005a	.039a
BLACK SPRUCE				
15	4.6a	0.036a	0.010a	0.046a
20	5.8b	.071c	.015b	.086c
25	7.4d	.094d	.017c	.111d
30	6.4c	.079c	.013b	.092c
35	5.5b	.050b	.010a	.060b

[1] Mean of 15 seedlings

[2] Means followed by common letters are not significantly different at P = 0.05 by Duncan's Multiple Range Test.

Table 2.--Height and dry weight[1] of jack pine, white spruce, and black spruce grown for 12 weeks in day temperature of 30°C and night temperature 15 - 30°C

Night temperature (C°)	Height	Dry weight: Shoot	Dry weight: Root	Dry weight: Seedling
JACK PINE				
	cm[2]	g	g	g
15	18.1a	0.600a	0.096a	0.696a
20	17.8a	.579a	.108a	.687a
25	16.4b	.591a	.105a	.696a
30	14.2c	.482a	.094a	.576a
WHITE SPRUCE				
15	8.0b	0.197b	0.042a	0.239ab
20	10.5a	.264a	.042a	.306a
25	9.1b	.215ab	.030a	.245ab
30	8.1b	.196b	.036a	.232b
BLACK SPRUCE				
15	12.4a	0.247b	0.036b	0.283b
20	13.7a	.357a	.051a	.408a
25	13.5a	.296ab	.041ab	.337ab
30	12.4a	.258b	.039ab	.297b

1 Mean of 15 seedlings.
2 Means followed by common letters are not significantly different at P = 0.05 by Duncan's Multiple Range Test.

was also strongly stimulated in the spruces and significant increases in shoot growth occurred in these species.

Table 3.--Mean weight and height of 15 conifer seedlings grown for 12 weeks in ambient and enriched CO_2 concentrations (day/night temperature: 30/15°C)

CO_2	Shoot weight	Root weight	Height
	g	g	cm
JACK PINE			
Ambient	0.60	0.10	18.1
Enriched	.53	.14	16.4
WHITE SPRUCE			
Ambient	0.20	0.04	8.0
Enriched	.24	.06	7.4
BLACK SPRUCE			
Ambient	0.25	0.04	12.4
Enriched	.34	.07	12.7

The results with jack pine are believed to be the result of higher humidity in the sealed cabinet (rh = 80 to 85 percent in the CO2-enriched cabinet compared to rh = 65 to 70 percent in the control cabinet). High humidity reduced evapotranspiration directly, both from the plants and from the soil surface. Seedlings were weighed every 2 or 3 days before watering; considerably less water was lost from seedlings in the enriched environment. Carbon dioxide enrichment induces stomatal closure which also reduces transpiration. The combined effect would be to promote water-logging in the soil and consequently to affect redox potential and nutrient exchange. Treatment seedlings of all three species were slightly chlorotic. Subsequent analysis revealed a total nitrogen content of between 11 and 33 mg/g in CO2-enriched plants compared to 20 to 25 mg/g for controls.

The fact that better results with CO2 enrichment were obtained with species of wetter habitats, and particularly with black spruce, supports the view that poor results with jack pine are more likely to be associated with soil moisture problems than with CO2 enrichment itself.

A second experiment was conducted with jack pine in which drying loops were linked to atmospheres in the control and CO_2-enrichment cabinets. Jack pine will respond positively to CO2 enrichment but humidity problems may arise (table 4). The need for more thorough experiments was obviated when OMNR nurserymen frequently found it necessary to augment the cooling system of greenhouses by ventilation which made enrichment impracticable.

Table 4.--Mean height and weight of 25 jack pine seedlings grown for 12 weeks in ambient and enriched CO2 concentrations at different relative humidities (day/night temperatures: 30/15°C)

CO_2	r.h.[1]	Shoot weight	Root weight	Height
		g	g	cm
		[2]		
Ambient	low	0.48a	0.15a	19.2a
Ambient	high	.54ab	.18ab	21.3a
Enriched	low	.68b	.30c	20.9a
Enriched	high	.54ab	.23bc	18.4a

1 low = 65 to 70 percent r.h.; high = 80 to 85 percent r.h.
2 Means followed by common letters are not significantly different at p = 0.05 by Duncan's Multiple Range Test.

Experiment 4--Effect of Photoperiod

Extended photoperiods affect growth in a variety of ways depending on the physiological state of the plant and on the intensity of light provided. Low intensity (less than 1,000 lux) extension of photoperiod will usually prevent the onset of dormancy in young seedlings and appears to stimulate growth by effects on plant metabolism. At higher intensities (above 10,000 lux) both of these effects will be present, but in addition is stimulated by the significant increase in energy available for photosynthesis. Natural photoperiods can be supplemented by low intensity light at reasonable cost, but the cost of installing and operating entirely artificial high intensity lighting is usually prohibitive for production nurseries.

This investigation was conducted in two parts. First, as a demonstration, seedlings were grown in four high intensity photoperiods. The experiment was then repeated with low intensity extensions of a fixed high intensity photoperiod.

High intensity photoperiod

Thirty-six seedlings of each species were reared in tubes at day/night temperatures of 25/20°C in each of four growth cabinets. The cabinets provided illumination of 22,000 lux for 15, 18, 21, and 24 h photoperiods, respectively, from a mixed source of fluorescent and incandescent lamps. As a precaution against unknown cabinet effects, the seedlings and treatments were rotated through the four cabinets at weekly intervals. The seedlings were harvested for growth measurement 8 weeks after sowing (table 5). All species grew faster under long photoperiods, with continuous light consistently yielding the heavier seedlings. Seedlings grown under continuous light were at least twice the weight of those grown under only 15 hours of light. The response of height growth was slight in all species. The shoot weight increase was principally in foliage.

Table 5.--Height and dry weight of jack pine, white spruce, and black spruce seedlings grown for 8 weeks in photoperiods of 15, 18, 21, and 24 hours of high intensity light (day/night temperature: 25/20°C)[1]

Photoperiod (h)	Height	Dry weight: Shoot	Dry weight: Root	Dry weight: Seedling
	cm	g	g	g
JACK PINE				
15	10.4a[2]	0.189a	0.062a	0.251a
18	10.8ab	.260b	.088b	.348b
21	11.4c	.331c	.127c	.458c
24	10.9b	.371d	.131c	.502d
WHITE SPRUCE				
15	4.8a	0.062a	0.011a	0.073a
18	5.0a	.080b	.015a	.095a
21	5.1a	.104c	.021ab	.125b
24	4.8a	.122d	.028b	.150c
BLACK SPRUCE				
15	6.5a	0.065a	0.014a	0.079a
18	6.7a	.090b	.021b	.111b
21	7.0a	.126c	.030c	.156c
24	6.7a	.145d	.033c	.178d

1 Mean of 36 seedlings
2 Means followed by common letters are not significantly different at p = 0.05 by Duncan's Multiple Range Test.

The cost of maintaining high intensity lighting is directly proportional to the duration of the photoperiod. But the response of seedling growth exceeds a simple linear relation: increasing photoperiod by 60 percent (from 15 to 24 hr) increased growth at least 100 percent. Thus in systems relying entirely on artificial lighting for high intensity illumination, long photoperiods are more efficient and more effective than short photoperiods.

Low intensity photoperiod

Eighteen seedlings per species were reared in each of four treatments for 10 weeks as for the high intensity experiment. Photoperiods were based on 14 h of high light intensity with 0, 2, 6, and 10 h of supplementary incandescent light of about 400 lux. The treatments and seedlings were rotated at weekly intervals (table 6).

Table 6.--Height and dry weight of jack pine, white spruce, and black spruce seedlings grown for 10 weeks in photoperiods[1] extended by low-intensity light (day/night temperature: 250/200C)

Photoperiod (h)	Height	Shoot	Root	Seedling
JACK PINE				
	cm	g	g	g
14 + 0	[2]12.3a	0.54a	0.20a	0.74a
14 + 2	13.1a	.43a	.19a	.62a
14 + 6	15.3b	.58a	.21a	.79a
14 + 10	15.1b	.57a	.19a	.76a
WHITE SPRUCE				
14 + 0	5.4a	0.063a	0.021a	0.084a
14 + 2	6.0ab	.075ab	.018a	.093a
14 + 6	6.0ab	.075ab	.018a	.093a
14 + 10	6.8b	.087b	.019a	.096a
BLACK SPRUCE				
14 + 0	8.3a	0.091a	0.018a	0.109a
14 + 2	8.1a	.098a	.021a	.119a
14 + 6	8.5a	.098a	.020a	.118a
14 + 10	8.2a	.105a	.018a	.123a

1 Mean of 18 seedlings.
2 Means associated by common letters are not significantly different at $p = 0.05$ by Duncan's Multiple Range Test.

Jack pine results were somewhat inconsistent, but there appeared to be some additional height growth under the long photoperiods. 'White spruce showed a steady, though moderate, increase in shoot weight and height growth while black spruce showed neither. In no species was root growth enhanced.

The additional growth of white spruce might justify photoperiod control. But results with other species do not support the use of low intensity photoperiod extension in the range tested. However, the base illumination of 14 h is comparable to photoperiods in mid-April and mid-August at the Swastika nursery. Attempts to rear seedlings earlier in the spring or later in summer would almost certainly require some low intensity extension of photoperiod to prevent early cessation of growth.

CONCLUSIONS AND RECOMMENDATIONS

The three northern conifers investigated--jack pine, black spruce, and white spruce--appeared to have similar requirements in the aerial environment. This simplifies the prescription for environmental control in nurseries rearing these species in plastic greenhouses.

The most suitable temperature for all three species is a 25°/20°C day/night regime. This is specific for spruces, yet lies within the broader range of 25-35°/15-25°C suitable for jack pine.

Photoperiodic effects can be divided into two broad categories, those related to development and those related to dry matter production. Even at low light intensities, photoperiod exercises great control over the development of a seedling. A short photoperiod will usually result in cessation of growth and the onset of dormancy; thus when natural day-lengths are critically short, photoperiods can be effectively and inexpensively extended through the use of low intensity incandescent lamps. But our results indicate that there is little gain in using very long photoperiods (more than 16 h) of low intensity supplements once the continuous growth of seedlings has been ensured.

The effectiveness of very long photoperiods would be different in systems employing high light intensity supplements. Additional light in the form of longer, high intensity photoperiods means more energy for photosynthesis and results in more and more dry matter growth; an increase in light of 60 percent (from 15 to 24 h) doubled dry matter growth in all three species in our experiment.

Daylength exceeds 14 hours between mid-April and mid-August at latitude 48°N and should not need supplementing. Photoperiod extensions earlier in spring and later in summer should maintain 14 hours of light. A preferable regime would be 16 hours of light, in view of the lesser vigour of greenhouse-grown seedlings.

The advantages of carbon dioxide enrichment depend largely on whether a greenhouse requires ventilation during hot weather. Concentrations up to 1,000 ppm or more are undoubtedly beneficial, especially when light intensities are high. But it is usually these conditions that call for ventilation to prevent excessively high temperatures. Carbon dioxide enrichment appears to be impracticable in summer in view of the limitations of cooling systems employed in many plastic greenhouses.

The prescription suggested for the aerial environment of a plastic greenhouse nursery is inexpensive to implement because both temperature and photoperiod optima are close to natural conditions. Implementation is simplified by the similar requirements of the three northern species, so that mixed or successive batches can be reared under the same conditions.

LITERATURE CITED

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