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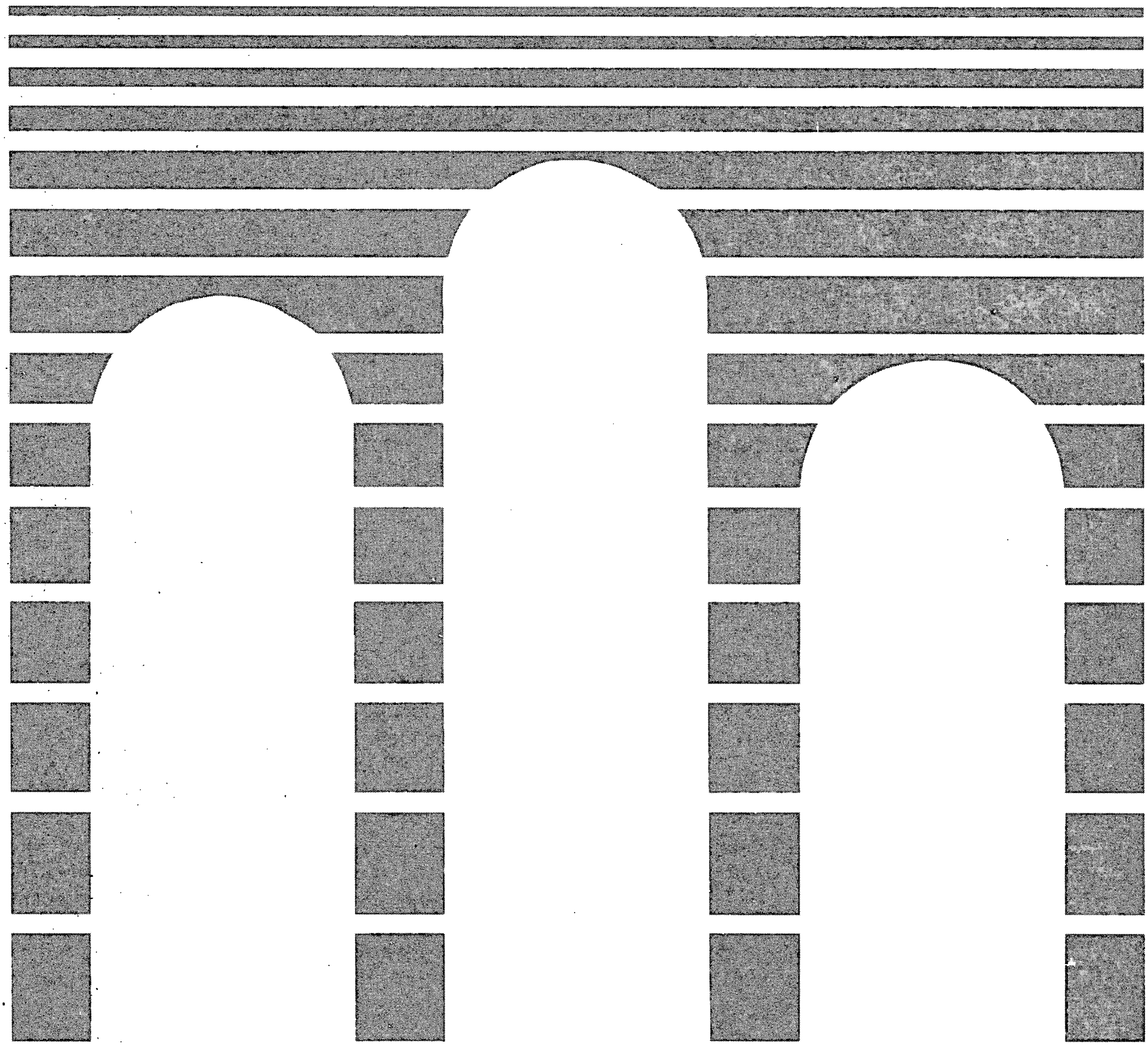

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GROWTH OF HYBRID POPLARS, WHITE SPRUCE, AND JACK PINE UNDER VARIOUS ARTIFICIAL LIGHTS

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Supplemental greenhouse lighting is used for two main reasons: (a) to extend the photoperiod and prevent plant dormancy, and (b) to stimulate growth. Low light intensity (less than 1,000 lux) will satisfy the photoperiod requirements of various coniferous species, whereas high light intensity (above 10,000 lux) is necessary to increase photosynthesis and growth (Pollard and Logan 1975).

Cathey and Campbell (1975) studied the effectiveness of 5 lighting sources on growth of 22 species of ornamental plants and concluded that incandescent (INC) light with red/far-red ratio similar to that of sunlight and high pressure sodium (HPS) were best for plant growth. In a later study with 32 species of foliage and flowering plants, Cathey and Campbell (1979) suggested that most light sources can create a near optimum growing environment if they provide 21 to 42 W/m^2 within the visible region.

Selection of a supplemental light source for a greenhouse should be based on both biological and economic (or energy consumption) considerations. Some lamps are more efficient than others in converting electrical energy into photosynthetically active radiation (PAR) (Campbell *et al.* 1971, Bickford and Dunn 1972, Norton 1973, Cathey and Campbell 1974). Moreover, the information on biological effects of some of the recently introduced lamps, such as HPS, is largely restricted to ornamental plants (Cathey and Campbell 1979). Very little is known how different lamps affect growth and development of trees.

The objective of our study was to evaluate energy consumption and effects of fluorescent, incandescent, and high pressure sodium lamps on growth and dry matter production of two hybrid poplars, white spruce, and jack pine.

METHODS AND MATERIALS

The tests were conducted in 1978 and 1979 in a greenhouse covered with a double-layer of polyethylene. The 1978 tests ran from December 1978 to April 1979, and the 1979 tests from August 1979 to January 1980. The day temperature in the plastic greenhouse was maintained from 21 to 25°C (70 to 77°F) and the night temperature from 18 to 21°C (64 to 70°F) except for some sunny days in August and September 1979 when the day temperature reached or surpassed 32°C (90°F). A uniform 18-hour photoperiod was assured by supplemental lighting.

Supplemental Light

Three supplemental light sources were compared: the incandescent (INC), fluorescent in combination with incandescent (FLU), and high pressure sodium (HPS). These light sources were mounted in fixtures as for normal greenhouse use. Four 150W very wide flood lamps were mounted 45 cm (18 in) apart and suspended 90 cm (36 in) above the bench. Two 40W cool white fluorescent tubes and two 25W incandescent lamps were mounted on a white-painted fixture made of sheet metal. This FLU fixture was also located 90 cm above the bench. The 250W HPS lamps were mounted in a reflector with a plexiglass diffuser. The bottom of the diffuser was about 120 cm (48 in) above the bench. The three light sources were located adjacent to each other and the entire setup was replicated three times at different locations in the plastic greenhouse.

The photosynthetically active radiation, PAR, was measured with quantum sensors connected to a quantum meter for instantaneous readings or to an integrator for cumulative readings. Spectral distribution of the light sources was obtained with a spectroradiometer over a range from 380 to 1,550 nm.

The mean, standard deviation (SD), and coefficient of variation (CV) of PAR provided by the individual light sources at the bench level directly beneath the fixtures were as follows (in uE/m^2•sec):

Light source	1978 Mean	1978 SD	1978 CV	1979 Mean	1979 SD	1979 CV
			Percent			Percent
INC	62.7	8.9	14	46.5	5.7	12
FLU	22.3	2.8	13	20.0	1.8	9
HPS	17.8	1.5	8	46.8	4.1	9

The HPS PAR intensity was increased in 1979 by changing from 110V to 220V. The PAR intensity of the INC light in 1979 was adjusted to that provided by the HPS lamps by raising the INC fixtures.

In spectral distribution the INC lamps were poor in blue but rich in both the red and far-red wavelengths. The spectral distribution of the FLU light (without the INC lamps) peaked around 500 nm and sharply decreased to shorter and longer wavelengths. The blues and reds were balanced but the intensity of the far-red was low and had to be boosted by the two 25W INC lamps. The HPS lamps featured several peaks in the visible spectrum, the most conspicuous ones between 550 and 600 nm, and several small peaks in the 750 to 1,550 nm region. Blues and reds were well balanced but in general the HPS light was rich in greens, yellows, and orange hues.

Daylight

About 60 percent of the PAR in incoming solar radiation reached the benches in the plastic greenhouse. Spectral distribution of PAR in the plastic greenhouse was similar to that measured outside. Daylight interception by the INC and HPS fixtures was low but on clear days the bulky FLU fixture intercepted more light than was provided by the FLU itself. A similar problem was also reported by Bickford (1967).

In both years, most of the PAR was provided by daylight. For example, in the 1978 study, daylight accounted for 80, 85, and 60 percent of the total PAR under the FLU, HPS, and INC lights, respectively.

Plant Materials

White spruce (*Picea glauca*), jack pine (*Pinus banksiana*), and two hybrid poplars, *Populus* 'Tristis # 1,' a cross between *P. tristis* and *P. balsamifera*, and a cross between *P. nigra* var. *betulifolia* and *P. trichocarpa*, were used in the study. The conifers were produced from seeds and poplars from 20 cm (8 in) hardwood cuttings. The conifers were transplanted into Hillson rootrainers (volume 150 cm^3). The growing media was 3 parts peat and 1 part each medium grade perlite and medium grade vermiculite. The rootrainers were strapped together to form blocks with 24 seedlings. The poplar hardwood cuttings were planted directly into Tubepak[1] II planters (volume 265 cm^3) whose growing medium was adjusted with lime to a pH 6.5. The tubepaks were strapped into blocks of 25 plants. One block of each species was placed under each of the three light sources.

The duration of the studies was:

Species	**1978**	**1979**
	------(Days)	------
Whitespruce	131	170
Jackpine	131	111
Populus 'Tristis # 1'	64	43
Populus nigra var. *betulifolia* x *P. trichocarpa*	—	28

The plants were watered daily. Slow release fertilizer was added to the growing media at the time of mixing. Both macro- and micronutrients were added to each growing media. Additional fertilizer was added after 3 months to the conifers which were grown for a longer time.

RESULTS

The 1978 Tests

These tests were conducted during the winter months when low level supplemental light was needed to extend the photoperiod and prevent plants from going dormant. The percentage of total PAR provided by the supplemental light was the same for jack pine and white spruce plants and averaged 17, 37, and 14 percent under the FLU, INC, and HPS lamps, respectively. In tests with *Populus* 'Tristis # 1' the corresponding percentages were 21, 43, and 18.

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[1] *The use of trade names does not constitute endorsement by the USDA Forest Service.*

The PAR of the three light sources was not considered high enough to promote appreciable dry matter accumulation. However, contrary to expectation, dry weight of plants under the INC light was significantly higher than dry weight of seedlings under the FLU and HPS lamps (table 1). Also heights of jack pine and hybrid poplar plants were significantly greater under the INC lamps. Dry weight of plants under the FLU and HPS lamps, which provided similar PAR levels, were not different. Height growth was inconsistent: hybrid poplars grew more under the HPS lamp, jack pine under the FLU lamp, and heights of white spruce plants were identical under these two light sources (table 1). Finally, leaf area per plant of hybrid poplar was statistically not different under the three light sources.

The 1979 Tests

In tests with *Populus* 'Tristis # 1,' the supplemental light provided only 8 percent of the total PAR under the FLU lamps and about 17 percent under both the INC and HPS lamps. Not surprisingly, the

Table 1.—*Growth of several woody species under different sources of supplemental light*

Light source	Mean	1978 Height	1978 Top dry weight	1978 Leaf area	1979 Height	1979 Top dry weight	1979 Leaf area
				POPULUS 'TRISTIS #1'			
		cm	*g*	*cm²*	*cm*	*g*	*cm²*
FLU[1]	Mean	[2]26.7[a]	1.85[a]	311[a]	36.0[a]	2.35[a]	504[a]
	SD[3]	7.4	.77	85	9.2	1.03	239
INC[4]	Mean	33.2[b]	2.50[b]	343[a]	40.8[b]	2.71[b]	594[a]
	SD	9.3	.89	115	11.3	1.07	129
HPS[5]	Mean	28.6[a]	2.03[a]	360[a]	40.0[b]	3.01[b]	502[a]
	SD	6.7	.80	142	8.3	1.16	167
				P. NIGRA VAR. *BETULIFOLIA* x *P. TRICHOCARPA*			
FLU	Mean	not available			17.5[a]	0.62[a]	171[a]
	SD				7.8	.47	61
INC	Mean	n.a.			27.5[b]	1.61[b]	230[a]
	SD				8.5	1.16	96
HPS	Mean	n.a.			25.6[b]	1.13[c]	196[a]
	SD				8.8	.65	114
				JACK PINE			
FLU	Mean	6.6[a]	0.36[a]	n.a.	8.5[a]	0.14[a]	n.a.
	SD	1.7	.17		3.0	.10	
INC	Mean	7.2[b]	.43[b]	n.a.	10.5[b]	.26[b]	n.a.
	SD	1.8	.20		4.1	.19	
HPS	Mean	5.7[c]	.36[a]	n.a.	8.9[a]	.22[b]	n.a.
	SD	1.3	.17		2.1	.11	
				WHITE SPRUCE			
FLU	Mean	7.0[a]	0.21[a]	n.a.	5.2[a]	0.06[a]	n.a.
	SD	1.3	.11		1.5	0.05	
INC	Mean	6.8[a]	.30[b]	n.a.	5.8[ab]	.12[b]	n.a.
	SD	1.5	.16		2.0	.11	
HPS	Mean	7.0[a]	.21[a]	n.a.	5.9[b]	.11[b]	n.a.
	SD	1.6	.11		1.7	.09	

[1]Fluorescent light (including two 25W incandescent lights) averaged 22.3 (± 2.8) and 20.0 (± 1.8) uE/m²•sec in 1978 and 1979 tests, respectively.
[2]Values (in columns) followed by the same letter are not significantly different (p = 0.05).
[3]Standard deviation.
[4]Incandescent light averaged 62.7 (± 8.9) and 46.5 (± 5.7) uE/m²•sec in 1978 and 1979 tests, respectively.
[5]High pressure sodium lamp provided 17.8 (± 1.5) and 46.8 (± 4.1) uE/m²•sec in 1978 and 1979 tests, respectively.

difference between the FLU plants and plants grown under the INC and HPS sources, although significant for both height and dry weight, was modest and may have resulted from an excessive daylight shading by the bulky FLU fixtures.

The role of daylight was less evident in jack pine and white spruce plants primarily because supplemental light provided a higher percentage of total PAR: 11, 22, and 22 percent for the jack pine and 13, 25, and 25 percent for the white spruce under the FLU, INC, and HPS lamps, respectively. Dry weights of the FLU plants were significantly and substantially lower than dry weights of either the INC or HPS plants (table 1). The INC and HPS plants were statistically not different. Height growth, although less conclusive, also was better under the INC and HPS lamps.

In the tests with *P. nigra* var. *betulifolia* x *P. trichocarpa*, supplemental light accounted for 21, 38, and 38 percent of the total PAR under the FLU, INC, and HPS lamps, respectively. This was reflected in dry weights and heights (table 1). Dry weights and heights of the FLU plants were significantly smaller than dry weights and heights of the INC and HPS plants. Also in the 1979 tests, leaf area per plant was not significantly different under the three light sources (table 1).

DISCUSSION

Results of our studies indicated a positive relation between total quantity of supplemental light and growth of test plants. For hybrid poplars the relation was exceptionally good and explained 88 percent of total variability. At the same PAR level no light source was biologically more efficient than the other. In the 1978 tests, the FLU and HPS lamps provided about the same PAR intensity and dry weights in all three species. Heights were more variable: the hybrid poplars grew taller under the HPS lamps, jack pine grew taller under the FLU lamps, and white spruce plants averaged the same under both sources. In the 1979 tests, similar patterns of dry weight and height growth were observed under the INC and HPS lamps with almost identical PAR levels. Broadly, these results were consistent with conclusions reached by Cathey and Campbell (1979) that any supplemental light source may provide a suitable environment for plant growth if the intensity is high enough.

The positive and consistent effect of supplemental light was unusual in view of the low intensity and relatively small percentage (8 to 40 percent) of the total PAR. These supplemental PAR levels were much lower than the 10,000 lux (290 uE/m^2•sec) proposed by Pollard and Logan (1975) as the minimum needed to appreciably stimulate photosynthesis and dry matter production. However, in other studies supplemental PAR as low as 1 ft-c (about 0.25 uE/m^2•sec) significantly affected the growth of seedlings of a number of tree species (Cathey and Campbell 1975) and PAR levels of only 0.21 uE/m^2•sec significantly affected growth of eastern white and Japanese black pines (Struve and Blazich 1980). In Arnott's (1979) nursery study, at 8 PAR levels ranging from 0 to 220 lux (about 4.7 uE/m^2•sec), heights and dry weights of all species were positively affected even at PAR levels of 5 lux (0.1 uE/m^2•sec) in comparison to the control. Contrary to this positive evidence on the effects of small PAR levels on plants growth, Pollard and Logan (1975) found no or little effect of a supplemental PAR of 400 lux (about 11 uE/m^2•sec) on the dry weight of jack pine and white and black spruce.

In both experiments, leaf area per plant of hybrid poplar did not vary significantly under the three light sources. This could mean that production of leaves is less affected by the type and intensity of supplemental light. However, other factors such as high variability of the data, small sample size, and chance allocation of atypical plants for leaf area determination could also be involved.

CONCLUSION

We concluded that none of the three light sources was biologically more effective than any other with equal PAR. This would include the FLU source if PAR were increased to levels comparable to those of the INC and HPS lamps and if the bulky metal sheet fixture were replaced with fixtures designed to produce minimum shading and maximum light output (Bickford 1967).

Whereas the biological effects of the individual supplemental light sources may be argued and certain lighting types may be preferred, the question of energy savings and economics is clear. Our spectroradiometric measurements over the 380 to 1,550 nm range showed that the INC, HPS, and FLU (without the INC) lamps converted respectively, 15, 66, and 91 percent of the total energy in that range into PAR. The INC lamps were obviously the most wasteful and uneconomical whereas both the FLU and HPS lamps were very efficient. The same conclusion has been reached in other studies (Campbell *et al.* 1971, Bickford and Dunn 1972, Norton 1973, Cathey and

Campbell 1974). The HPS lamps have the additional advantage of a long lifespan which according to one manufacturer averages 24,000 hours.

To provide a reasonably uniform PAR distribution on a 120-cm (48-in) wide bench, the FLU and INC fixtures should be mounted crosswise (only 3 INC 150W floods per fixture) about 90 cm (36 in) above the bench and spaced about 100 to 120 cm (40 to 48 in) apart. The HPS fixtures would be mounted 120 cm (48 in) above the bench and be spaced 2 m (80 in) apart. Under these conditions the FLU lighting would provide 20 to 28 uE/m^2•sec, the INC about 40 to 60 uE/m^2•sec and the HPS about 45 to 60 uE/m^2•sec at the bench level. The electric energy drain per linear meter of bench would be 450, 110, and 140W for the INC, FLU (with two 25W INC lamps) and HPS lamps, respectively. The HPS lighting would reduce electricity consumption and cost to about one-third compared to an INC setup. Additional electricity and cost economy would be achieved with the FLU lighting but the PAR would be only half that provided either by the INC or HPS lamps.

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Describes the energy consumption and biological effects of fluorescent, incandescent, and high pressure sodium lighting on the growth of poplars, white spruce, and jack pine in a greenhouse. At similar light levels the biological effects of all three light sources were similar. The incandescent lamps consumed several times more energy than the other two light sources.

KEY WORDS: Photosynthetically active radiation (PAR), height growth, dry matter production, plastic greenhouse.

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