

Run for Cover! What's Covering Your Greenhouse and How Is It Affecting Seedling Growth?

Jeremy R. Pinto
R. Kasten Dumroese
John D. Marshall

Jeremy R. Pinto is Tribal Nursery Coordinator, USDA Forest Service, Southern Research Station, 1221 S. Main St., Moscow, ID 83843; telephone: 208.883.2352; e-mail: jpinto@fs.fed.us. R. Kasten Dumroese is Research Plant Physiologist, USDA Forest Service, Southern Research Station, 1221 S. Main St., Moscow, ID 83843; telephone: 208.883.2324; e-mail: kdumroese@fs.fed.us. John D. Marshall is Professor, University of Idaho, College of Natural Resources, Department of Forest Resources, PO Box 441133, Moscow, ID 83843; telephone: 208.885.6695; e-mail: jdm@uidaho.edu

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Abstract: Analysis of seedling growth characteristics between two greenhouse cover types, old fiberglass and new polycarbonate, shows significant differences in height and sturdiness coefficients in ponderosa pine (*Pinus ponderosa*) seedlings. Three rates of nitrogen (N) application (20, 40, and 60 mg) indicate that seedling growth will increase under both cover types, but may cause a reduction in seedling quality attributes including shoot-to-root ratio and seedling sturdiness. Under the new polycarbonate cover type, the mid and high rates of N fertilizer application showed no significant gains in seedling growth. Significant differences in germination were also detected between the two cover types favoring the old fiberglass material. When considering replacing a greenhouse cover with a new material, it is important to consider alterations in the seedling growth environment and make the appropriate cultural adjustments to ensure high seedling quality.

Keywords: greenhouse cover, greenhouse glazing, light, seedling growth, *Pinus ponderosa*

Introduction

The greenhouse environment has long been used for the rapid establishment of outplantable trees for reforestation. Over the years, the variety of propagation environments has increased to suit the demands of growers and clients to produce the optimal target seedling. Despite the vast variety of propagation structures available, greenhouses have maintained a common set of properties to achieve a favorable growing environment. The ideal greenhouse environment utilizes cover materials that favor the capture of sunlight while maintaining temperature, humidity, and CO₂ for a specified crop (Nijskens and others 1985; Landis and others 1994). More specific ideal radiometric properties call for maximal transmittance in the photosynthetically active radiation (PAR) spectrum (400 to 700 nm) and minimal transmittance in the far-infrared spectrum (>1,000 nm) to produce the desired “greenhouse effect” (Nijskens and others 1985).

Greenhouse cover materials, or glazings, come in numerous varieties, each with its unique set of properties as they relate operationally and physically. Table 1 summarizes three commonly used types of material. When planning to build or re-cover a greenhouse, certain considerations should be made regarding cost, life span, strength, weight, light transmittance, and thermal conductance (Landis and others 1994; Evans 2003).

Each of these properties plays a critical role in greenhouse structure, but long-term planning should consider the effects of life span and light transmittance. Typically, shorter life span materials will cost less, allowing for regularly scheduled replacement. In cases where material remains in place longer than its life span, specifically fiberglass cover materials, significant reductions in light transmittance can be observed. Therefore, with one of the four atmospheric components (light, humidity, carbon dioxide, and temperature) necessary for growth in limiting supply, optimal seedling growth can be compromised (Kozlowski and Pallardy 1997). To fully understand the consequences of a reduced light growing environment, a review of the nature of light is necessary.

Table 1—Operational and physical considerations of three common greenhouse cover types (adapted from Landis and others 1994; Evans 2003).

Material	Operational considerations		Light (%PAR)	Thermal conductance (BTU loss/ft ² /hr/(ΔF))	□ Lifespan years
	Advantage	Disadvantage			
Fiberglass	Low cost, strong, light-weight	Surface degrades easily, highly flammable	90 single layer	1.2	3–10
			70 double layer	<1.2	3–10
Polyethylene	Low cost, light-weight, easy to install	Short life, high thermal conductance	85 single layer	1.2	2–3
			76 double layer	0.7	2–3
Polycarbonate	High impact resistance, low flammability	High cost, high expansion and contraction	94 single layer	>0.5	20–25
			83 double layer	0.5	20–25

The electromagnetic radiation emitted from our sun covers a broad spectrum of wavelengths from high energy, short wavelength ultraviolet rays to low energy, long wavelength radio waves (Grossnickle 2000; Larcher 2003). Within this range of wavelengths, three properties of light (intensity, duration, and quality) are known to influence the two physiological plant growth factors of photosynthesis and photomorphogenesis, defined below (Kozłowski and Pallardy 1997; Grossnickle 2000; Larcher 2003). Wavelengths ranging from 400 to 700 nm are collectively categorized into the visible spectrum and are also associated with photosynthetically active radiation (PAR). Photosynthesis produces chemical energy for plant growth and metabolism with signature wavelengths peaking at 430 and 680 nm; these wavelengths are captured by carotene and chlorophyll pigments (Landis and others 1994). Morphological development, including branching, shoot elongation, shoot sturdiness, seed germination, and budset, are influenced by the visible and near infrared light spectrum (700 to 1000 nm) via phytochrome and other pigments. These responses are termed photomorphogenesis (Landis and others 1992; Grossnickle 2000). Of the four atmospheric factors that influence seedling growth, photosynthesis and photomorphogenesis are highly influenced by the light aspect, but photosynthesis is also influenced by temperature (Landis and others 1992).

As temperature increases, photosynthesis also increases curvilinearly. At the same time, the reciprocal process of respiration increases exponentially. As long as total photosynthesis exceeds respiration, net photosynthesis is positive. When the maximum temperature for photosynthesis is reached, however, the net photosynthetic gain will be lower than the respiration rate. Depending on different types of greenhouse cover types, and their thermal conductance capabilities, different temperatures within the greenhouse will have a significant impact on seedling growth as illustrated by this principle (Landis and others 1992).

Changes in greenhouse cover type can have a significant impact on seedling growth as illustrated by modifications of the light environment and the subsequent effects of changes in temperature. Our study objective was to examine the direct effects of an old fiberglass greenhouse cover and a new polycarbonate cover on seed germination and seedling growth. The addition of three fertilizer treatments provided information on the degree at which nutrient availability would

compensate for shade effects. Direct effects measured are morphological traits including height, root collar diameter (RCD), seedling biomass, shoot-to-root ratio, and sturdiness coefficient. Examinations of germination percentages and rates, light absorption spectra, and light quality will supplement findings in the direct effects.

Materials and Methods

Nursery Culture

Ponderosa pine (*Pinus ponderosa* Laws. var. *ponderosa*) seedlings from an Idaho Department of Lands seed source (850 m [2,790 ft] elevation; seedlot CO85) were grown at the University of Idaho Center for Forest Nursery and Seedling Research (UI) in Moscow, Idaho (46° 43'N, 117° 00'W). Seedlings were sown in a 2 by 3 factorial design with three replicates per treatment. Treatments consisted of two cover types and three fertilizer rates. Six small growing structures were constructed using the two cover types. Three structures were built from old fiberglass (approximately 25 years old) belonging to the previous UI greenhouse, and the remaining three were constructed from the new twin-wall polycarbonate material used on the newly erected UI greenhouse (figure 1). Each structure represented a replicate containing each of the three fertilizer treatments. Structural dimensions were approximately 1.5 by 0.7 by 0.9 m (5 by 2.3 by 3 ft) with a single 45° sloped roof.

The north side of each structure remained open for ventilation and had a removable plastic cover to protect seedlings from cold nighttime temperatures. The remaining three sides were covered by the respective greenhouse cover with the exception of approximately 15 cm (6 in) at the bottom for ventilation. All structures were elevated above ground on a wire mesh bench. Stratified seeds were hand sown 21 May, 2002 into Styroblock™ 315B containers having a 90-ml (5.5-in³) volume and 756 m² (70.6 ft²) density (Beaver Plastics, Edmonton, Alberta) and containing a sphagnum peat moss:vermiculite (1:1, v:v) medium (Sun Gro Horticulture, Bellevue, Washington). Target® Forestry Nursery Grit (Target Products Ltd., Burnaby, British Columbia) was used to cover the freshly sown seeds. Cavities were thinned to one seedling 2 weeks after sowing.



Figure 1—Six small growing structures, three made from old fiberglass and three made from new polycarbonate, used to produce *Pinus ponderosa* seedlings for one growing season at the University of Idaho Center for Forest Nursery and Seedling Research, Moscow, Idaho.

Fertilizer treatments were divided into three levels of total nitrogen (N) applied: 20, 40, and 60 mg. Exponential fertilization was carried out for the duration of the experiment. The basic formula for exponential fertilization is

$$N_T = N_S (e^{rt} - 1)$$

where r is the relative addition rate required to increase N_S (initial N content in plant) to a final N content ($N_T + N_S$) where N_T is the desired amount to be added over t , the number of fertilizer applications (Ingestad and Lund 1986; Timmer and Aidelbaum 1996). Using an estimate of 0.5 mg for N_S , 119 days for t , and the target N_T value (20, 40, and 60 mg), the relative addition rate r was calculated for each treatment, 0.031, 0.037, and 0.040 respectively. The amount to apply on a specific day was calculated using

$$N_T = N_S (e^{rt} - 1) - N_{t-1}$$

where N_T is the amount of N to apply daily, N_{t-1} is the cumulative amount of N applied, and t goes from 1 to 119.

Because root exploitation of the growth substrate is lacking immediately after germination, compensation for the small amount of N applied during the first 2 weeks was calculated using

$$N_C = N_S (e^{rt} - 1)$$

where N_C is the mg of N to compensate, N_S is the initial N content in the plant, r is the relative addition rate, and t equals the compensation period (assumed 14 days). For all three treatments, N_C equaled the cumulative amount N scheduled to be applied on days 118, 119, and 120 (1.9, 4.4, and 7.2 mg N rates for 20, 40, and 60 mg N applied, respectively). The daily amount of N compensated was calculated using

$$N_T = N_S (e^{rt} - 1) - N_{t-1}$$

where t went from 14 to 0. Therefore, plants received N_T plus N_C for the first 14 days and no additional fertilizer on days 118, 119, and 120. Intervals between fertigation events

varied, so daily N_T values were summed with the cumulative amount applied when irrigation was necessary. N treatments were fertigated with 20N:7P₂O₅:19K₂O (Peters Professional® Conifer Grower™, The Scotts Company, Marysville, Ohio), and application was gravimetrically determined (White and Marstalerz 1966; Landis and others 1989).

Sampling

Germination was recorded for each experimental unit for 38 days after sowing and used to calculate five germination parameters: germination capacity (GC), peak value (PV), germination value (GV), germination value prime (GV'), and germination rate prime (GR'₅₀). As a measure of germination completeness, GC was calculated as the total number of germinants over the entire measured period. PV, a measure of germination speed, is the maximum value obtained using

$$PV = DCG/\text{days since start of test}$$

where DCG is the daily cumulative percent germination (Czabator 1962). GV combines germination speed and completeness calculated by

$$GV = (GC/D) * PV$$

where D is the number of days in the test. GV', a refinement of Czabator's (1962) GV, is calculated by

$$GV' = (\sum PV/N) * GC * 10$$

where N equals the number of observations used to determine PV (Djavanshir and Pourbeik 1976). GR'₅₀ is equal to the number of days required for 50 percent of the seeds to germinate (Ching 1959).

Morphological measurements including height, root collar diameter (RCD), and seedling biomass were obtained from 20 seedlings at the end of the growing season (mid-November). Shoots and roots were separated and dried to a

stable weight at 60 °C (140 °F) to determine seedling biomass. Shoot-to-root ratios were calculated for each seedling by dividing shoot biomass by root biomass. Sturdiness coefficients, another form of expressing the shoot-to-root relationship (Burdett and others 1984), were calculated for each seedling by dividing height (cm) by RCD (mm). Trees with lower sturdiness values signify seedlings that are more robust and less prone to mechanical damage (Scagel and others 1998).

Light

Photosynthetically active radiation (PAR) was measured for each greenhouse cover type on 11 June, 2002 between 1435 and 1456 hours. Six measurements were made in each replicate with the terminal cell of a ceptometer (Decagon Instruments, Pullman, WA). The spectral distribution of solar irradiance was measured for each greenhouse cover type and for full sun. Measurements were taken with a LI-COR 1800 spectroradiometer (from 300 to 850 nm with a spectral resolution of 2 nm). Radiation measurements were taken 10 September, 2002 between 1115 and 1135 hours. The LI-COR receptor was placed 12 cm (5 in) from the back of the growing structure between the Styroblock™ containers elevated to the height of the seedling canopies. Three measurements were made for each structure and the outside full sun.

Statistical Analysis

The general linear model of the Statistical Analysis System (SAS Institute Inc 2003) was used to analyze data. Analysis of variance and multiple comparisons, with Tukey-Kramer inequality adjustments, were completed for height, RCD, and biomass to test for fertilizer and cover type effects ($\alpha = 0.05$). Analysis of variance were completed for germination data to test for cover type effects ($\alpha = 0.05$). T-test analysis was used on PAR measurements ($\alpha = 0.05$). Assumptions for equal variances and normality were met by all data analyzed.

Results

Germination

Cover type data analysis showed the old fiberglass higher in GC, PV, GV, and GV' compared with new polycarbonate

(table 2). Total germination was 9 percent higher under the old fiberglass; however, the number of days to 50 percent germination (GR'_{50}) showed no significant difference. Other indices (PV, GV, and GV') indicate a slower germination rate under the new polycarbonate greenhouse cover type.

Light, Cover, and Fertilizer Effects

New polycarbonate covers yielded a mean PAR measurement of 1014 $\mu\text{mol}/\text{m}^2/\text{s}$ (standard error = 31.5), and the old fiberglass cover measured 727 $\mu\text{mol}/\text{m}^2/\text{s}$ (standard error = 116.5). T-test analysis showed no significant difference at $P = 0.08$. Analysis of variance showed no significant cover x fertilizer interactions for any measured morphological characteristic. No cover effects were observed for RCD, shoot biomass, root biomass, total seedling biomass, or shoot-to-root ratio ($P > 0.18$); however, cover effects were seen in height and sturdiness coefficient ($P < 0.01$; figure 2). Significant fertilizer effects were seen for all morphological measurements with the exception of sturdiness coefficient ($P < 0.02$; table 3). Fertilizer treatments showed increased growth with increased N application. Tukey pairwise analysis detected no differences between the 40 and 60 mg N treatment rates for height, RCD, root dry weight, or shoot-to-root ratio (table 3).

Discussion

The results of Li and others (1994) showed that light has a positive effect on the germination rates and values of ponderosa pine seeds; however, this effect was not seen in this study. It was expected that germination rates and values for the new polycarbonate structure would be the same as, if not higher, than the old fiberglass structure. It is hypothesized that temperature may have been a key component in the difference of values, but unfortunately, the temperature data were lost. Therefore, we are left to speculate that more radiation, higher temperatures, and drier conditions contributed to less germination under the new polycarbonate structures. Future studies should monitor temperature and soil moisture conditions in response to elevated greenhouse temperatures, which may improve germination parameters.

Trends for increasing height, RCD, and seedling biomass in response to fertilizer treatments were expected and observed (Reed and others 1983; van den Driessche 1991). The fact that RCD, shoot biomass, root biomass, and total seedling biomass illustrated no differences between cover types

Table 2—Mean, standard error, and P -values for germination parameters between two greenhouse cover materials: new polycarbonate and old fiberglass ($\alpha = 0.05$).

Material	Cumulative germination GC (%)	Indices of germination speed			
		PV	GV	GV'	GR'_{50}
New polycarbonate	75	3.2	6.5	17	12
Old fiberglass	82	4.1	9.1	24	11
Standard error	2.12	0.20	1.73	0.56	0.51
P -value	0.02	0.01	0.01	0.01	0.11

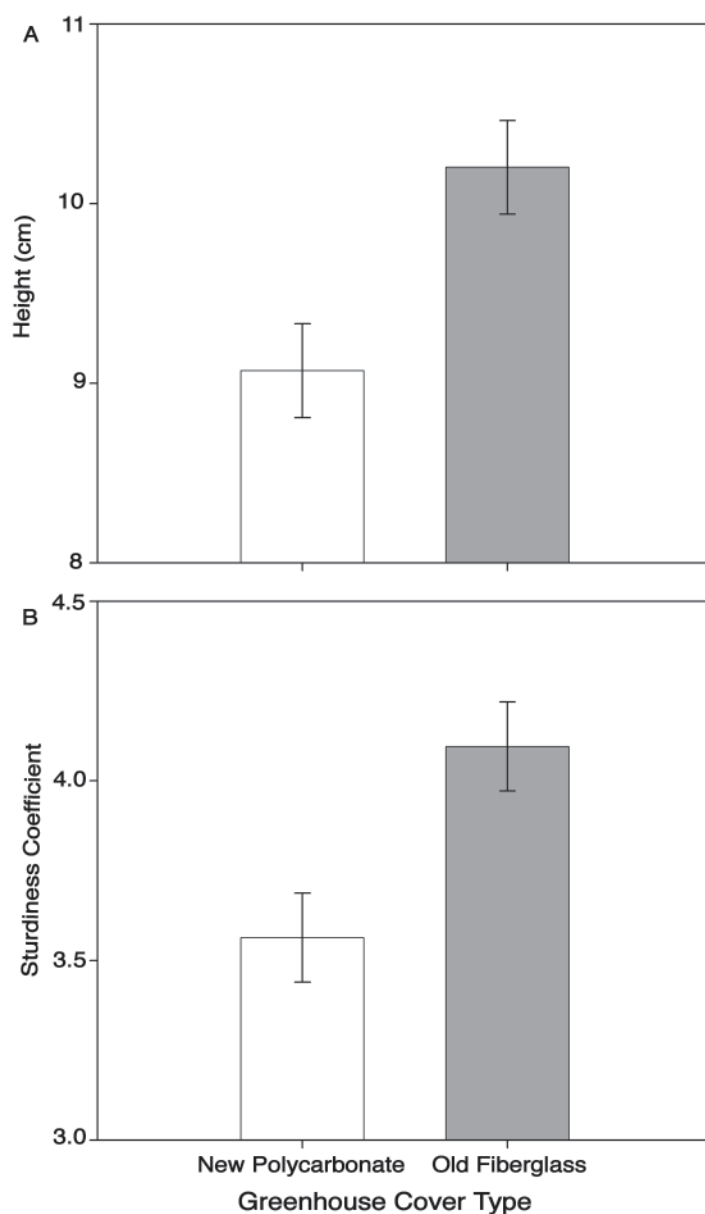


Figure 2—Seedling height (A) and sturdiness coefficient (B) under two greenhouse cover types after one growing season (bars indicate standard error).

Table 3—Mean, standard error, and *P*-values of seedling morphological characteristics under three fertilizer treatments (means with the same letters are not significantly different; $\alpha = 0.05$).

Fertilizer (mg N applied per seedling)	Height	RCD	Shoot dry weight	Root dry weight	Total dry weight	Shoot-to-root ratio
	<i>cm</i>	<i>mm</i>	<i>g</i>			
20	8.44 a	2.29 a	0.60 a	0.60 a	1.20 a	1.02 a
40	9.88 b	2.59 b	0.80 b	0.69 b	1.49 b	1.18 ab
60	10.58 b	2.73 b	0.89 c	0.73 b	1.62 c	1.25 b
Standard error	0.32	0.04	0.02	0.02	0.03	0.05
<i>P</i> -value	<0.01	<0.01	<0.01	<0.01	<0.01	0.01

was unexpected. The spectral irradiance data shows three distinct patterns of distribution (figure 3), with the sun having the largest magnitude and the old fiberglass cover with the lowest (statistical analysis not performed), but the t-test analysis of PAR showed no statistical differences ($P = 0.08$) between cover types.

This may partly explain the lack of cover type differences seen in the morphological measurements. Although seedlings grown under the old fiberglass structures were significantly taller overall, their total seedling biomass was not significantly different from that of seedlings grown under the polycarbonate structure. From the literature, the increased height suggests that seedlings may have etiolated under the slightly lower light conditions (Bartlett and Remphrey 1998). Under the conditions of this study, it may be speculated that conditions of the growing structures did not adequately capture the differences in growth and lighting for full greenhouse environments as seen by Tuller and Peterson (1988) in Douglas-fir (*Pseudotsuga menziesii*). It may also be speculated that because the growing structures were open on one side, the nature and transmission of the cover materials may have been overcome by side light, thereby minimizing morphological differences between seedlings.

A more indepth examination of seedling biomass and shoot-to-root ratios would help to understand the relationship of etiolation and reduced light effects on seedling quality;

however, due to the interaction seen in the analysis of cover type x fertilization on root biomass and shoot-to-root ratio, interpretation for this study is difficult. It is notable that at the 40 mg N fertilization rate, no difference was seen between cover types in RCD, root biomass, shoot biomass, total seedling biomass, and shoot-to-root ratio. At the 60 mg N rate, differences arise in root biomass and shoot-to-root ratio creating a seedling that may not meet target seedling quality criteria under the reduced light, old fiberglass environment. Tuller and Peterson (1988) found similar results in greenhouse-grown Douglas-fir seedlings under 4-year-old fiberglass and new polyethylene cover types. An examination of sturdiness coefficients, as a lone measure of seedling quality, shows that seedlings grown in the high light environment exhibit desirable target seedling qualities.

Summary

Although differences between cover types in this study were few, results illustrate the importance of monitoring and adjusting cultural treatments when changes occur in light intensity. In situations where greenhouses exhibit low light quality or quantity, due to an old greenhouse cover type, it is important to consider the implications of correcting for low seedling quality with increased nutrient regimes.

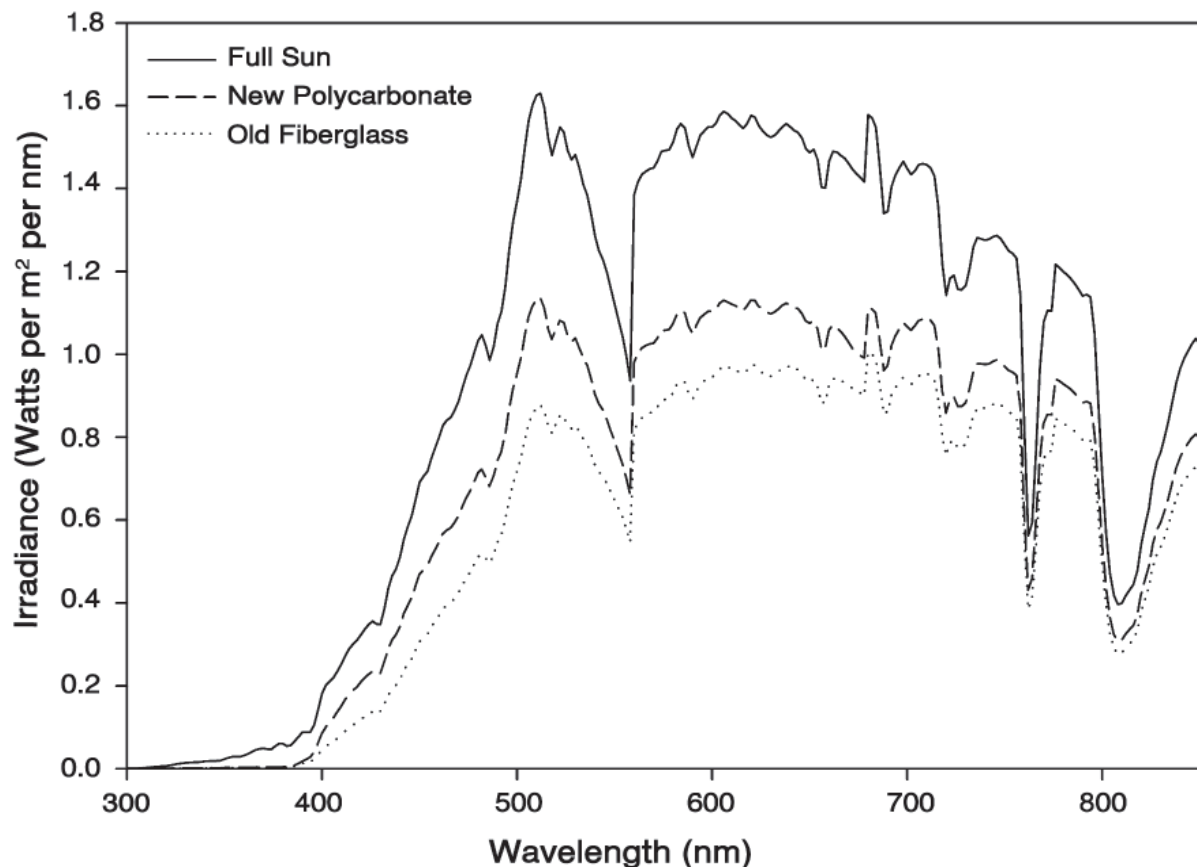


Figure 3—Spectral distribution from 300 to 850 nm of solar irradiance under full sun, new polycarbonate, and old fiberglass in Moscow, Idaho (46° 43'N, 117° 00'W), 10 September, 2002.

Conversely, under new greenhouse covers that exhibit good light quality and quantity, it is also important to consider changes in atmospheric conditions such as temperature, and adjustments to cultural applications such as nutrient regimes.

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