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Duplicating Foliage Shade for Research on Plant Development

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***Abstract.* A shade film is described which duplicates the spectral quality of light underneath foliage. The film should become an important tool for studying plant development, and it may have commercial applications.**

We are beginning to understand the ecological significance of phytochrome for plant development, beyond that of controlling flowering (17). Progress has been frustrated, however, by difficulties in experimental methodology. The quantity and spectral quality of radiation passing through foliage is altered by the optical properties of leaves. Leaves typically absorb 90% of incident light in the wavelengths 400–700 nm and less than 10% of radiation 750–1100 nm (7, 8, 20). Thus, natural light under foliage is deficient in radiation usable for photosynthesis, and is spectrally altered in the wavelengths (650–750 nm) affecting phytochrome equilibria (1, 10, 18). Although shade light may affect plant growth and development profoundly (3, 9, 13, 14, 17), it has been difficult to document its effects because of the heterogeneity of natural light environments (2, 15, 16), and the difficulty of producing artifical ones (17).

Research on the effect of spectral distribution of radiation on plant growth has been hampered by the necessity of including adequate levels of photosynthetic photon flux density (400–700 nm, or PPFD) along with altering the quantum ratios of red to far-red wavelengths [660/730 nm, or R:FR as defined by Smith (17)]. The high R:FR characteristic of sunlight is achieved easily through the use of fluorescent or mercury vapor lamps. However, only moderately low R:FR can be achieved by the use of low wattage tungsten incandescent lamps. This radiation can be altered further by filters (8, 9, 16), but the excess infra-red radiation from the high flux

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Received for publication 5 July 1984. Commercial use of the shade film described in this article will be regulated by a pending patent. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

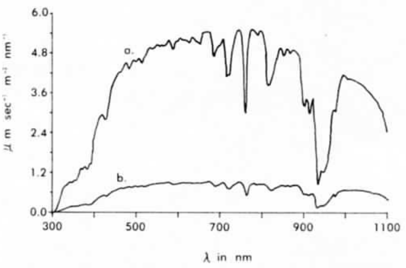

Fig. 1. Spectral distribution of radiation between the wavelengths of 300–1100 nm, in units µmol $s^{-1}m^{-2}nm^{-1}$. **a**. Full sunlight. **b**. Commercial shade house with 83% shadecloth.

densities required to achieve minimal PPFD requires heat filtration and limits the size of the growth chamber. A method for altering sunlight (or an artifical radiation source) to provide levels of PPFD and ratios of R:FR very similar to those under natural shade is described.

To design and construct a film with the necessary optical properties, it was necessary to determine the relationship between shading (percentage of PPFD) and spectral quality (R:FR) in shade films and screens compared to radiation beneath foliage. For this purpose, a LI-COR 1800 spectroradiometer (LI-COR Instruments, Lincoln, NE 68504) with a wavelength response of 300–1100 nm and a half peak bandwidth of 6 nm was employed for all measurements. Spectra were determined at intervals of 2 nm. Quantum integration of each scan at 400–700 nm gave PPFD in µmol s^{-1} m^{-2}. Quantum ratios (658–662/728–732 nm) gave R:FR. Outdoor measurements were performed within 1 hr of solar zenith in full sunlight, in November of 1983. Effects of foliage shade on PPFD and R:FR were measured under isolated trees on the Tamiami Campus of Florida International Univ. and under the closed canopy of a hardwood hammock at Simpson Park in Miami. Radiation conditions under various commercial shade cloths and films were measured at 15 commercial nurseries in southern Dade County in July of 1983. For the preparation and evaluation of the shade film, various pigments and combinations thereof were screened for their similarity in spectral quality to natural shade. The pigments were mixed in a urethane varnish base and sprayed on 22 × 28 cm sheets of cellulose acetate. These sheets were analyzed spectrally under full sunlight by affixing them to a 20 × 26 cm opening on a flat black box 16 cm above the sensor.

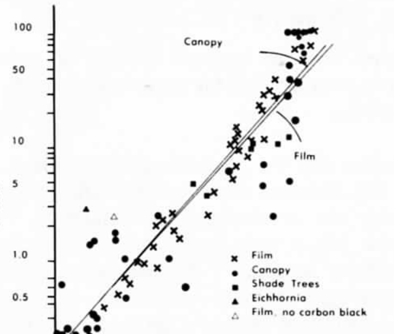

Fig. 2. Relationship between R:FR and percentage of full sunlight underneath individual tree canopies, means of 5 measurements for each variety (■); under a closed forest canopy (●), n = 39; and underneath varying densities of the shade film (**x**), n = 38. Values indicating the spectral alteration of radiation immediately beneath water hyacinth leaves (*Eichhornia crassipes* Solms.) are indicated by (▲), and values for the film without the addition of carbon black are shown by (△). Points are the means of 5 measurements. Regression lines for hammock and shade film measurements also are given.

Full sunlight measured in this study had a mean R:FR of 1.270 (SD of 0.039, from 24 scans). Commercial shading materials (115 different growth environments analyzed) did not change the spectral distribution of radiation significantly (Fig. 1) and thus had R:FR's identical to full sunlight for all percentages of shading. Shade light underneath foliage was characterized by decreasing R:FR in relationship to decreasing percentages of full sunlight (Fig. 2).

The above results made possible the development of an artificial film that duplicates the properties of natural foliage, from screening many different pigments and combinations. The best shade film is a combination of the following (Fig. 3): 1 part Hostaperm Violet RL pigment; 0.25 parts of Solvaperm Yellow G dye (both obtained from American Hoechst, Inc., Coventry, RI 02816); and 0.40 parts of carbon black pigment. These materials were sprayed routinely on films in a concentration of 10% w/v. These pigments meet 3 important criteria for successful use in constructing outdoor shade environments for studying plant development. First, they are relatively inexpensive. Second, they are stable to both high temperatures and light levels, giving them a long field life and the possibility of incorporation into plastic film (S. Kumar, personal communication). Thirdly, they have the desired spectral characteristics (Fig. 2, 4). Increased pigment density alters R:FR just as the increased shading of thicker foliage does, and extreme shade underneath the artifical film is very similar to that underneath foliage at identical percentages of full sun PPFD. It also is feasable to alter the R:FR of the film for a given percentage of shade by changing the concentration of the spectrally neutral carbon black pigment. For instance, the spectral quality immediately beneath leaves of water hyacinth is altered substantially (Fig. 2), and this shift can be approximated by using the 2 compounds without carbon black.

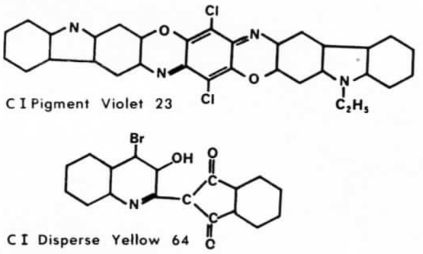

Fig. 3. Structural identification of compounds used for altering spectral distribution of light in the shade film.

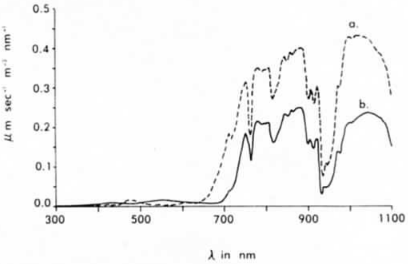

Fig. 4. Spectral distribution of radiation, same units as Fig. 1. **a**. Under a closed forest canopy in Simpson Park. **b**. Underneath the shade film.

These pigments, applied as a paint or incorporated in a film, should have wide application in research on plant development in response to light. Long-term studies typically have used different densities of shade cloths or levels of artificial light, neglecting the important spectral shift of radiation in increasing shade under natural conditions (4, 5, 6, 10, 11, 19). Two enclosures, with identical percentages of shading but with R:FR of full sunlight vs. deep forest shade, now can be constructed to study the effects of spectral quality vs. radiation intensity on long-term developmental responses of plants of small to large stature. The pigments also can be sprayed onto small plastic bags to study the effects of altered spectral quality on a small portion of a plant. The film also could be used to alter the spectral quality of the cool tungsten lamps used in measurements of photosynthesis, producing radiation close to that of natural conditions for measuring the photosynthetic responses of extreme shade plants (12). If the film enhances the growth or quality of foliage plants, or other plants, it may have commercial applications.

Literature Cited

1. Björkman, O. and M.M. Ludlow. 1972. Characterization of the light climate on the floor of a Queensland rainforest. Carnegie Institution Yearb. 71:85–94.
2. Chazdon, R.L. and N. Fetcher. 1984. Photosynthetic light environments in a lowland tropical rain forest in Costa Rica. J. Ecol. 72(2):553–564.
3. Child, R., D.C. Morgan, and H. Smith. 1981. Morphogenesis in stimulated shadelight quality. In: H. Smith, ed. Plants and the daylight spectrum. Academic Press, London.
4. Conover, C.A. and R.T. Poole. 1977. Effects of cultural practices on acclimatization of *Ficus benjamina* L. J. Amer. Hort. Sci. 102:529–531.
5. Fetcher, N., B.R. Strain, and S.F. Oberbauer. 1983. Effects of light regime on the growth, leaf morphology, and water relations of seedlings of two species of tropical trees. Oecologia 58:314–319.
6. Fonteno, W.C. and E.L. McWilliams. 1978. Light compensation points and acclimatization of four tropical foliage plants. J. Amer. Hort. Sci. 103:52–56.
7. Gates, D.M., H.J. Keegan, J.C. Schleter,

and V.R. Weidner. 1965. The spectral qualities of plants. Appl. Optics 4:11–20.

8. Gausman, H.W. and W.A. Allen. 1973. Optical parameters of leaves of 30 plant species. Plant Physiol. 52:57–62.
9. Hébant, C. and D.W. Lee. 1984. Ultrastructural basis and developmental control of blue iridescence in *Selaginella* leaves. Amer. J. Bot. 71:216–219.
10. Holmes, M.G. 1981. Spectral distribution of radiation within plant canopies. In: H. Smith (ed.). Plants and the daylight spectrum. Academic Press, London.
11. Jurik, T.W., J.F. Chabot, and B.F. Chabot. 1982. Effects of light and nutrients on leaf size, CO_2 exchange, and anatomy in wild strawberry (*Fragaria virginiana*). Plant Physiol. 70:1044–1048.
12. McCree, K.J. 1981. Photosynthetically active radiation. Encyclopedia of plant physiology series II. Physiological plant ecology, I. Springer Verlag, Heidelberg.
13. Morgan, D.C. 1981. Shadelight quality effects on plant growth. In: H. Smith (ed.). Plants and the daylight spectrum. Academic Press, London.
14. Morgan, D.C. and H. Smith. 1981. Nonphotosynthetic responses to light quality. Encylopedia of plant physiology, series II. Physiological plant ecology, I. Springer Verlag, Heidelberg.
15. Pearcy, R.W. 1983. The light environment and growth of C_3 and C_4 tree species in the understory of a Hawaiian forest. Oecologia 58:19–25.
16. Reifsnyder, W.E., G.M. Furnival, and J.C. Horowitz. 1970. Spatial and temporal distribution of solar radiation beneath forest canopies. Agr. Met. 9:21–37.
17. Smith, H. 1982. Light quality, photoreception and plant strategy. Annu. Rev. Plant. Physiol. 33:481–518.
18. Tasker, R. and H. Smith. 1977. The function of phytochrome in the natural environment. V. Seasonal changes in radiant energy quality. Photochem. Photobiol. 26:487–491.
19. Williams, S., S. Wolf, and E.J. Holcomb. 1983. Growth and flowering of *Exacum affine* at three radiant energy levels. HortScience 18(3):366–367.
20. Woolley, J.T. 1971. Reflectance and transmittance of light by leaves. Plant Physiol. 47:656–662.