BOT. GAZ. 149(4):361–364. 1988.

BIOLOGICAL AND PHOTOMETRIC MEASUREMENT OF LIGHT TRANSMISSION THROUGH SOILS OF VARIOUS COLORS

M. J. KASPERBAUER AND P. G. HUNT

U.S. Department of Agriculture, Agricultural Research Service, Coastal Plains Soil and Water Conservation Research Center, P.O. Box 3039, Florence, South Carolina 29502-3039

We measured light penetration photometrically and biologically through black, brown, brick-red, tan, and gray-white soils. Less than 0.005% of the incident light penetrated 4 mm of the dark-colored or 10 mm of the gray-white soils. Light-requiring (LR) and light-indifferent (LI) tobacco seeds were used for biological measurement of light through 2, 4, 6, 8, and 10 mm of each of the five soils. The LR seeds were used to measure light-penetration effects on germination, and LI seeds were used as controls to determine whether the seed had sufficient reserves for seedlings to emerge from the various depths. The germination studies were conducted in a controlled environment with daily 12-h light periods from cool-white fluorescent lamps at 20 C. About 99% of the LR seeds germinated in light and 0% when covered with 4 mm or more of the dark-colored soils. Germination for the LI seeds was ca. 98% in light or when covered with 4 mm of any color of soil.

Introduction

Soil surface color influences seedling light environment and plant development patterns (KASPERBAUER and HUNT 1987). Plants grown over white surfaces develop relatively short, thick stems and many lateral roots compared with plants grown over black surfaces (HUNT et al. 1985). However, the precise role of soil color on lateral root development is unclear. There are several possibilities: (1) light might enter the shoots and be transmitted through stem tissue to an active photoreceptor in the roots, (2) light absorbed by the shoots might initiate a change in endogenous growth regulator balance that affects stem length suppression and release of lateral root inhibition, or (3) light penetration through the soil to the root zone might act directly on the roots.

MANDOLI and BRIGGS (1982) showed that light can be transmitted within plant tissue. They suggested that certain tissues can act as light transmitters, analogous to a fiber optic cable. VOGELMANN and BJORN (1984), using fiber optic probes in plant tissue, found that filtering and light-scattering effects of plant tissue caused change in spectral balance of light as it moved through tissue. LOCKHART (1964), LETHAM (1967), and KASPERBAUER (1971) discussed effects of various wavelengths of light on endogenous growth regulators and a possible role in plant development. Direct transmission of light through soil to regulate biological events has received less attention.

Our study was conducted with black, brown, brick-red, tan, and gray-white soils to measure (1) photometrically, the amount and spectral distribution of light that penetrates soil of various colors, and (2) biologically, light transmission through various depths of the same soils. Light-requiring and light-indifferent tobacco seed selections were used for the biological measurements to avoid light transmission through plant tissue, as might occur if roots of intact plants were used.

Manuscript received March 1988; revised manuscript received June 1988.

Address for correspondence and reprints: M. J. KASPERBAUER, USDA-ARS, P.O. Box 3039, Florence, South Carolina 29502-3039.

Material and methods

Light transmission was measured through various depths of five different colors of soil. Measurements were made photometrically with a LiCor-1800 Spectroradiometer[1] with a remote light collector, and biologically with light-requiring (LR) and light-indifferent (LI) tobacco (*Nicotiana tabacum* L.) seed selections (KASPERBAUER 1968*a*).

Color, nomenclature, and source of the various soils are shown in table 1. A standard Munsell Soil Color Chart was used to describe soil color. The soils were all steam sterilized at 121 C and 1 kg cm^{-2} for 20 min to kill weed seeds before the experiment began. Soils were air-dried on a greenhouse bench and pulverized to pass a 0.6-mm sieve.

For photometric measurements, transparent plastic film was first stretched over the remote light collector to provide a lower limit for the layer of soil; then premarked black plastic sides were taped to the light collector to provide a 2-mm-deep trough for the soil. In succession, each of the five soil colors was measured for light transmission through 2 mm of soil. The 2-mm depth markers were then replaced by 4-mm depth markers, and the process was repeated for all soils. Similarly, light-transmission measurements were taken through 6, 8, and 10 mm of each soil. The measurements were taken

[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

TABLE 1

COLOR, NOMENCLATURE, AND SOURCE OF SOILS

VISUAL APPEARANCE	MUNSELL COLOR CODE		NOMENCLATURE	SOURCE
	Hue	Value/Chroma		
Black	7.5 YR	2/0	Canisteo silty clay loam (Typic Haplaquolls)	Ames, Ia.
Brown	10.0 YR	4/3	Maury silt loam (Typic Paleudalfs)	Lexington, Ky.
Brick-red ...	2.5 YR	4/6	Pacolet clay (Typic Halpludults)	Chesnee, S.C.
Light tan ...	10.0 YR	5/2	Norfolk loamy sand (Typic Paleudults)	Florence, S.C.
Gray-white ..	10.0 YR	6/1	Rimini sand (Entic Haplohumods)	Coward, S.C.

under sunlight on a cloudless day at solar noon ± 0.5 h. Light measurements were taken at 5-nm intervals from 400 to 850 nm. A scan of direct sunlight was used as a reference to express transmission percentages through the various colors and thicknesses of soil. For each soil color and depth, light transmissions were first made through dry soil. The soil was then moistened with water using a spray mist applicator, and measurements were taken through moist soil.

Biological measurements of light transmission used the LR selection of tobacco seed described in an earlier report (KASPERBAUER 1968*a*). None of the LR seed germinated in uninterrupted darkness on either moist filter paper or moist soil. However, after 1 day under moist conditions at 20 C, more than 98% of the LR seed germinated in response to a single 5-min exposure to white or red light followed by uninterrupted darkness at 20 C. An LI selection of tobacco seed (KASPERBAUER 1968*a*) was used as a control to determine whether tobacco seedlings had sufficient reserves to emerge through the various depths of soil. The LI selection gave ca. 98% germination in either light or uninterrupted darkness at 20 C in preliminary experiments.

Plastic cups were used as containers for biological measurements of light transmission. Two lines were drawn with a Sanders marking gauge around the inside circumference of each cup. The upper one was 5 mm below the upper rim of the cup. The other was either 2, 4, 6, 8, or 10 mm below the upper line. Premoistened horticultural potting soil was placed in each cup to the lower line and leveled to provide the same conditions for both seed selections under all soil colors. In each cup 100 precounted seeds were placed and immediately covered to the upper line with the appropriate color of soil, which was moistened with a spray mist to avoid altering the thickness of the soil layer. There were five replicate cups of 100 precounted seeds each for each of the five soil colors and six depths (0, 2, 4, 6, 8, and 10 mm) for both LR and LI seed. After seeding, the cups were arranged in boxes and covered with transparent plastic to minimize drying and disturbance of the soil surface. All containers were kept on a laboratory bench at 20 C. The laboratory was dark for the first 18 h. All pots were then illuminated for 12 h/day with cool-white fluorescent lamps. The diurnal cycle of 12-h light alternated with 12-h darkness was repeated each day for the duration of the experiment. Light at the soil surface of all treatments was 450 μmol m^{-2} s^{-1}. Seedlings were counted once per day and removed by cutting just below the cotyledons. This procedure allowed an accurate record of emergence and did not disturb the soil layer. Values for germination are presented as means ± SE for the five replicate cups for each treatment.

Results and discussion

Plants grown over black surfaces develop long internodes and few lateral roots, while those grown over white surfaces develop short, thick stems and many lateral roots (HUNT et al. 1985). The effects of soil surface color and reflected light on plant growth patterns have been attributed to several factors, including amount of reflected photosynthetically active light and to photomorphogenic light which regulates partitioning of photosynthate among plant components (KASPERBAUER 1988). Absorption of upwardly reflected blue, red, and far-red light by the shoots and action via altered endogenous growth regulator balance might be influential in shoot and root development patterns (KASPERBAUER 1987). However, direct penetration of light into the soil warrants examination as a possible regulator of lateral root growth.

LIGHT TRANSMITTED THROUGH SOIL

To influence root growth or seed germination, light transmitted through soil might act directly on the roots or seeds, or the light might possibly affect soil microbes and microbial balances which affect root growth and/or seed germination. In our study, we used steam-sterilized soil to remove the possible microbial factor, and LR seed to measure a direct biological response to light transmitted through soil without the possible influence of light transmitted from shoots to roots.

PHOTOMETRIC MEASUREMENTS.—Light transmission through the darker soils was extremely low,

and the greatest light penetration was through the gray-white sandy soil (table 2). Spectral distributions of sunlight were compared at the soil surface and under 4 mm of moist gray-white soil (fig. 1). Percentages of sunlight (measured at 5-nm intervals from 400 to 850 nm) transmitted through 4 mm of moist gray-white soil increased with increasing wavelength (fig. 2). Light transmission through as little as 2 mm of the darkest and 10 mm of the lightest soils was below detection limits of the spectroradiometer (table 2).

BIOLOGICAL MEASUREMENT.—The study involved spray mist–moistened soils to maintain a moist surface while minimizing soil disturbance, and a constant 20 C, which is favorable for germination of tobacco seed (KASPERBAUER 1986*a*, 1986*b*). Even under these favorable conditions, as little as 2 mm of the dark-colored soils blocked the light needed to trigger germination of LR seed (table 3). Some germination of the LR seed occurred under 6–8 mm of the gray-white soil, which is consistent with photometric measurements (table 2). Germination and emergence of the LI selection showed that the seeds had sufficient reserves for the seedlings to emerge through 6–8 mm of any of the moist soils after germination.

High germination of LR seeds above the soil and emergence of LI seedlings through several millimeters of any of the soils are evidence that even thin layers of dark soil were sufficient to block the light required to trigger germination of LR seed, even when other factors such as temperature and moisture were favorable.

Results with LR seed showed that light penetration of 4 mm of dark-colored soil and 10 mm of the gray-white soil was inadequate to trigger a biological response such as seed germination (tables 2, 3). In an unpublished experiment with soybean (*Glycine max* L.) seedlings, we inserted a light-tight barrier below a 10-mm layer of various colors of soil but above the root zone. Plants grown over near-white soil had shorter stems and heavier root systems with more lateral roots. Thus, the photo-

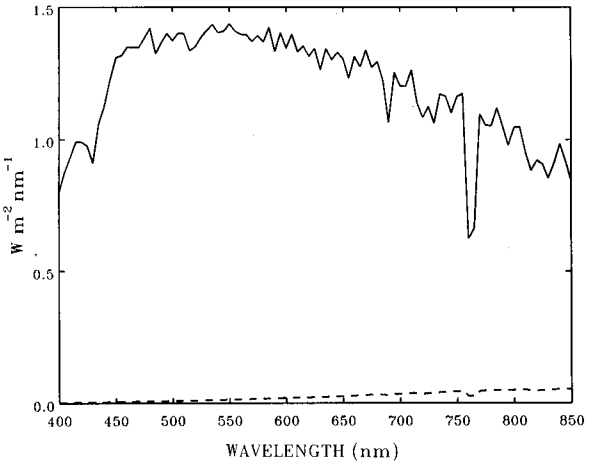

FIG. 1.—Spectral distribution of sunlight at the soil surface (solid line) and after transmission (broken line) through 4 mm of moist gray-white soil. Light measurements were taken at 5-nm intervals from 400 to 850 nm.

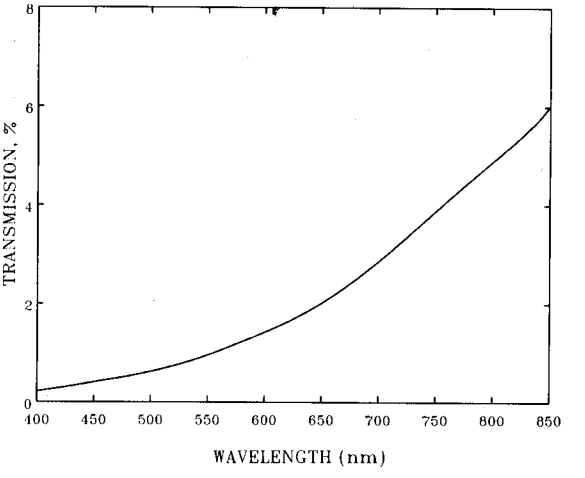

FIG. 2.—Percentages of incident sunlight (at 5-nm intervals) that penetrated through 4 mm of moist gray-white soil. Light measurements were taken at 5-nm intervals, and each value is expressed as percentage of the light received at the same wavelength above the soil surface.

TABLE 2

PHOTOMETRIC MEASUREMENT OF LIGHT (μmol m^{-2} s^{-1}) TRANSMITTED THROUGH 2, 4, 6, 8, OR 10 mm OF MOISTENED BLACK, BROWN, BRICK-RED, TAN, OR GRAY-WHITE SOILS

DEPTH OF SOIL COVER (mm)	SOIL COLOR				
	Black	Brown	Brick-red	Tan	Gray-white
2	<.10[a]	<.10	.12	.21	58.83
4	<.10	<.10	<.10	<.10	22.71
6	<.10	<.10	<.10	<.10	3.58
8	<.10	<.10	<.10	<.10	.55
10	<.10	<.10	<.10	<.10	<.10

[a] About 1,800 μmol m^{-2} s^{-1} of incident light were received at the soil surface.

TABLE 3

BIOLOGICAL MEASUREMENT OF LIGHT TRANSMITTED THROUGH 0, 2, 4, 6, 8, OR 10 mm OF BLACK, BROWN, BRICK-RED, TAN, OR GRAY-WHITE SOILS

DEPTH OF SOIL COVER (mm)	SOIL COLOR				
	Black	Brown	Brick-red	Tan	Gray-white
LR seed:					
0	99.6 ± 0.3[a]	99.2 ± .4	99.2 ± .4	99.0 ± .6	99.0 ± .3
2	1.4 ± .3	2.0 ± .8	<1.0	7.8 ± 2.3	98.6 ± .4
4	.0	.0	.0	<1.0	96.0 ± 3.0
6	.0	.0	.0	<1.0	58.5 ± 5.0
8	.0	.0	.0	.0	9.0 ± 5.1
10	.0	.0	.0	.0	<1.0
LI seed:					
0	98.2 ± .9	98.6 ± .7	98.8 ± .4	98.8 ± .6	98.6 ± .2
2	96.2 ± 1.8	98.4 ± .5	98.2 ± .4	98.8 ± .4	97.4 ± .8
4	98.4 ± .4	98.2 ± .5	...	97.4 ± .6	97.2 ± 1.2
6	98.2 ± 1.1	96.0 ± 1.6	69.0 ± 4.6	91.8 ± 2.2	91.8 ± 2.7
8	94.6 ± 1.6	95.0 ± .5	65.6 ± 5.8	76.0 ± 4.9	56.6 ± 12.3
10	42.2 ± 3.1	9.8 ± 3.7	6.0 ± 1.8	11.3 ± 1.7	30.4 ± 9.0

[a] Values are mean percentages ± SE for seedling emergence of five lots of 100 seeds each. In a companion experiment using water-moistened filter paper in petri dishes in a 20 C controlled-environment chamber, the LR selection germinated 98.8% in light and 0% in uninterrupted darkness, whereas the LI selection germinated 97.4% in light and 96.8% in uninterrupted darkness.

metric and biological measurements of light transmitted through soils and the unpublished experiment with the light barrier below a white soil support the concept that soil surface color effects on root growth patterns result from effects of upwardly reflected light, which is absorbed by the photomorphogenic receptors in the shoots and then initiates events that regulate shoot and root characteristics.

Knowledge of the effects of light transmitted through and/or reflected from various colors of soil is important in understanding the effect of soil color on plant growth and productivity. The probability of direct effects of light transmitted through soil on development of higher plants seems minimal relative to the effects of the quantity and spectral distribution of upwardly reflected light. Our recent research on use of different colored plastic mulches for high value horticultural crops is an application of this knowledge (DECOTEAU et al. 1987).

Acknowledgment

We thank W. SANDERS and J. E. FRICK for technical assistance.

LITERATURE CITED

DECOTEAU, D. R., M. J. KASPERBAUER, and P. G. HUNT. 1987. The influence of plastic mulch color on plant light environment and tomato seedling development. HortScience **22**:1099.

HUNT, P. G., M. J. KASPERBAUER, and T. A. MATHENY. 1985. Effect of soil surface color and *Rhizobium japonicum* strain on soybean seedling growth and nodulation. Agronomy Abstr. **85**:157.

KASPERBAUER, M. J. 1968*a*. Dark-germination of reciprocal hybrid seed from light-requiring and light-indifferent *Nicotiana tabacum*. Physiol. Plant. **21**:1308–1311.

———. 1968*b*. Germination of tobacco seed: inconsistency of light sensitivity. Tobacco Sci. **12**:20–22.

———. 1971. Spectral distribution of light in a tobacco canopy and effects of end-of-day light quality on growth and development. Plant Physiol. **47**:775–778.

———. 1987. Far-red light reflection from green leaves and effects on phytochrome-mediated assimilate partitioning under field conditions. Plant Physiol. **85**:350–354.

———. 1988. Phytochrome involvement in regulation of the photosynthetic apparatus and plant adaptation. Plant Physiol. Biochem. **26**(4):519–524.

KASPERBAUER, M. J., and P. G. HUNT. 1987. Soil color and surface residue effects on seedling light environment. Plant and Soil **97**:295–298.

LETHAM, D. S. 1967. Chemistry and physiology of kinetin-like compounds. Annu. Rev. Plant Physiol. **18**:349–364.

LOCKHART, J. A. 1964. Physiological studies on light sensitive stem growth. Planta **62**:97–115.

MANDOLI, C. F., and W. R. BRIGGS. 1982. The photoreceptive sites and the function of tissue light-piping in photomorphogenesis of etiolated oat seedlings. Plant Cell Environ. **5**:137–145.

VOGELMANN, T. C., and L. O. BJORN. 1984. Measurement of light gradients and spectral regime in plant tissue with a fiber optic probe. Physiol. Plant. **60**:361–368.