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Soybean Seedling Growth Responses to Light Reflected From Different Colored Soil Surfaces

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ABSTRACT

Spectral balance (quality) of light influences many aspects of plant growth and development; and spectral balance of reflected light in the seedling establishment zone is affected by the color of soil surfaces, plant residues, and mulches. Soybean [*Glycine max* (L.) Merr.] seedlings were grown over white, red, and black surfaces in greenhouse studies. Painted insulation panels, cloth-covered insulation panels, and different colored soils over insulation panels were used to test the effects of reflected light while minimizing root zone temperature differences. Reflected light from 400 to 800 nm was measured at 5-nm intervals and expressed as the percentage of direct sunlight at each measured wavelength. Photosynthetically-active light (400–700 nm) reflected from the white and black surfaces was about 40 and 5%, respectively, of that in direct sunlight. Blue light (400–500 nm) was reflected at about 40% from white and 5% from either black or red panels. Red surfaces reflected similarly to the black from 400 to 570 nm and similarly to the white from 620 to 800 nm. Soybean seedlings were grown in 1-L containers of vermiculite mounted below the insulation panels, inoculated with *Bradyrhizobium japonicum*, and supplied with N-free nutrient solution. Plants grown over white surfaces developed the shortest stems, the most lateral roots and nodules, and the smallest shoot:root dry matter ratios. The amount of blue light as well as the far-red/red ratio in reflected light contributed to these morphogenic effects. It was concluded that the surface color of soil can substantially alter the growth and nodulation of soybean seedlings even though root zone temperatures under various surface colors are similar.

PLANT SPACING and row orientation of soybean can affect canopy light spectral balance (quality), as well as quantity, which affects not only the amount of photosynthate produced but also the partitioning of that photosynthate among shoots, roots, and nodules (Kasperbauer, 1987). Light received by soybean shoots also affects the autoregulation of nodulation (Kosslak and Bohlool, 1984; Hunt et al., 1987). Hunt et al. (1985) reported that the response of soybean yield to row orientation was influenced by the strain of *B. japonicum*, and they suggested that the effect was associated with the light environment of the shoots during growth of the host plant. Thus, shade, day length, and row orientation have all been considered in regard to light management for soybean growth and nodulation.

Reflectors have been used to increase canopy light quantity and to alter plant growth (Pendleton et al., 1967; Dufault and Wiggans, 1981). Also, soil surface and plant residue color were recently recognized as contributors to variations in seedling light environment (Kasperbauer and Hunt, 1987). Differences in light reflected from black vs. white surfaces were sufficient to cause very dramatic and consistent differences in stem length of southern pea [*Vigna unguiculata* (L.) Walp.] even though soil temperatures below the black and white surfaces were within 1 °C of each other.

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The objectives of the present study were to determine if soil surface color could affect soybean shoot and root morphological development and the amount of nodulation.

MATERIALS AND METHODS

Greenhouse experiments were conducted to determine effects of reflected light from various soil surface colors on soybean seedling growth. Dow[1] Styrofoam brand (Dow Chemical Co., Midland, MI) insulation panels (122 × 122 × 2 cm) were used in all experiments to minimize root zone temperature differences below the various surface colors. For all experiments, pregerminated seeds were planted when the radicles were approximately 5 mm in length, inoculated with 10^8 cells of *B. japonicum* (USDA 3I1B110), and grown in 1-L containers that were attached below the colored surface. The containers were filled with horticultural-grade vermiculite and watered as needed with 0.25-strength N-free nutrient solution.

All plants within the same experiment received the same amount of water and nutrients. Each liter of nutrient solution contained the following mg of each compound: 609 $CaCl_2$, 495 $MgSO_4 \cdot 7H_2O$, 135 KH_2PO_4, 435 K_2SO_4, 1.4 H_3BO_3, 0.04 $CuCl_2 \cdot 2H_2O$, 0.9 $MnCl_2 \cdot 4H_2O$, 0.1 $ZnCl_2$, 0.02 $H_2MoO_4 \cdot H_2O$, and 9.4 Fe EDTA in deionized water. Each plant grew through a 2-cm hole in the insulation panel, and the experimental apparatus was designed so that air circulated freely around the plant containers below the insulation panels. Temperatures within the containers were measured at 1-min intervals with copper-constantan thermocouples and a Campbell CR7 Datalogger (Campbell Science, Inc., Logan, UT).

Upwardly reflected light was measured 10 cm above the surface at 5-nm intervals from 400 to 800 nm with a Li-Cor 1800 Spectroradiometer (Li-Cor, Inc., Lincoln, NE) with the light collector on a 1.5-m fiber optic probe. Spectral irradiances at 735 nm and 645 nm were used to calculate the far-red relative to red light ratios (FR/R) because these wavelengths are the FR and R phytochrome action peaks, respectively, in green plants (Kasperbauer et al., 1964). The photosynthetic photon flux density (PPFD), FR/R photon ratio, and blue light in upwardly reflected light 10 cm above the variously colored surfaces are shown in Table 1. This height above the soil is important because it is in the seedling establishment zone.

Soybean plants in all experiments were sampled 28 d after planting, and the following parameters were measured: (i) stem length, (ii) stem dry weight, (iii) tap and lateral root weight, (iv) tap and lateral root nodule number, and (v) tap and lateral root nodule weight. All weights were obtained after freeze drying. All data were analyzed by analysis of variance (ANOVA) and least significant difference (LSD) as

[1] Mention of trademark, proprietary product, or vendor anywhere in this paper does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

outlined by the SAS Institute (1985). Details that differed among experiments are outlined below.

Experiment 1

Plant growth responses to light reflected from painted insulation panels were studied in a greenhouse in January 1985. A split-split-plot design with four replications was used. Surface color was the main plot treatment, and soybean cultivar was the split-plot treatment. Surface colors were obtained by painting the foam panels red, white, or black. Two soybean cultivars (Braxton and Davis, Maturity Groups VII and VI, respectively) were used. Six plants, three of each cultivar, were grown on each panel at 30-cm intervals.

Experiment 2

Bare and oat (*Arena sativa* L.) straw residue covered soils were the reflective surfaces of a second study, which used a randomized complete block design with four colors and three replications in February 1986. The soil containers were 2.5-cm-deep plywood boxes whose bottoms were covered by 122 × 122 × 2-cm Styrofoam insulation panels. Four 2-cm holes were drilled in the insulation and box bottoms to allow passage of plants through 2-cm diam plastic pipes that extended from the container of vermiculite below the insulation panel, and through the panel and the layer of soil. White Rimni (sandy, siliceous, thermic Grossurenic Entic Haplohumod), brick-red Pacolet (sandy, siliceous, thermic Typic Humaquept), and near-black Rutlege (sandy, siliceous, thermic Typic Humaquept) soils were used to supply the surface colors. In one treatment, black soil was covered with dry oat straw to simulate an 85% crop residue cover, as frequently occurs in conservation tillage. Braxton soybean plants were used.

Experiment 3

The effects of two levels of reflected blue light (400–500 nm) on soybean seedling growth were studied in this experiment by the use of yellow and light blue fabrics covering the surface of the panels. The two fabrics reflected almost identical PPFD and FR/R ratios. However, about 75% of the blue in direct sunlight was reflected from the blue surface while only 15% of the blue in direct sunlight was reflected by the yellow surface. The study was repeated three times between November 1986 and May 1987, and the data were pooled for analyses. Soybean cultivar, inoculant strain, and experimental procedures were the same as used in Exp. 2.

Table 1. Characteristics of upwardly reflected light 10 cm above red, white, and black-painted panels used in Experiment 1 and above red, white, black, and oat straw residue-covered soil used in Experiment 2.

Experiment	Surface color	Upwardly reflected light†		
		PPFD	FR/R	Blue
		— μmol m^{-2}s^{-1} —	— ratio —	— % —
1–Painted panels				
	Red	211	1.00	5
	White	714	0.84	42
	Black	81	0.83	5
2–Soil-covered panels				
	Red	56	0.91	7
	White	129	0.85	38
	Black	30	0.94	7
	Residue	75	1.03	9

† PPFD = photosynthetic photon flux density, FR/R = ratio of photons received at 735 nm divided by photons received at 645 nm, Blue = the amount of reflected blue (400–500 nm) light expressed as a percentage of incident blue light.

RESULTS AND DISCUSSION

Experiment 1

Root zone temperatures were similar under all three surface colors; daily mean temperatures were 21.7, 22.0, and 22.3 °C below the white, red, and black surfaces, respectively. Maximum temperature variations at any given time were less than 3 °C. Temperature effects are an integral aspect of how plants respond to phytochrome action, and our procedures were designed to minimize these effects. The white and the black surfaces reflected about 40 and 5% of the incoming sunlight, respectively (Table 1). The red surface reflected similarly to the black surface in the 400 to 570 nm portion of the spectrum and similarly to the white surface from 620 to 800 nm. Percentages of blue light (400–500 nm) reflected from white, red, and black surfaces were about 40, 5, and 5%, respectively. The FR/R ratio over the red surface was slightly higher than the ratio over the white and black surfaces.

The two soybean cultivars responded similarly to surface color (a nonsignificant cultivar × color effect). Therefore, data for soybean cultivars were pooled within each surface color treatment. Plants grown over white surfaces developed shorter but thicker stems than plants grown over black surfaces (Table 2). These shoot growth data are similar to those reported by Kasperbauer and Hunt (1987) for southern pea in field studies with the same colors on insulation panels in row middles.

Tap, lateral, and total root weights were significantly greater for plants with the white surface treatment than with the black surface treatment. Lateral roots of seedlings grown over white surfaces had significantly more and heavier nodules than roots of seedlings grown over either red or black surfaces.

Table 2. Shoot and root growth and nodule characteristics of soybean seedlings grown over different colored insulation panels.

Plant characteristic	Panel surface color			LSD (0.05)
	White	Red	Black	
Shoot				
Stem length, mm	70	79	89	9
Stem weight, mg	83	79	66	NS
Root				
Tap weight, mg	37	28	25	8
Lateral weight, mg	160	135	110	49
Total weight, mg†	242	195	157	76
Root nodules				
Tap, no.	8	8	7	NS
Lateral, no.	31	22	13	7
Tap weight, mg	16	17	13	NS
Lateral weight, mg	28	15	10	11
Shoot:root weight ratio	1.51	1.74	1.86	0.28

† Total root weights include nodules.

Table 3. Shoot and root growth and nodule characteristics of soybean seedlings grown over different colored soils and oat straw residue covering insulation panels.

Plant characteristic	Soil surface color: White	Red	Black: Bare	Black: Residue	LSD (0.05)
Shoot					
Stem length, mm	127	138	141	159	14
Stem weight, mg	137	120	120	136	15
Root					
Tap weight, mg	38	38	39	37	NS
Lateral weight, mg	220	151	161	156	41
Total weight, mg†	293	213	222	217	36
Root nodules					
Tap, no.	5	6	4	4	NS
Lateral, no.	36	26	32	34	NS
Tap weight, mg	6	7	5	5	NS
Lateral weight, mg	29	17	17	19	11
Shoot:root weight ratio	1.48	1.69	1.57	1.75	0.22

† Total root weight includes nodules.

Nodulation of the tap root was not affected by surface color. As a consequence of the different growth pattern, the shoot:root ratio of the plants grown over white surfaces was significantly lower than the ratio for plants grown over the black surfaces. Additionally, the white vs. black and red single degree of freedom contrast for shoot:root ratio was significant ($P \leq 0.03$).

The higher weights per plant that developed with the white surface appear to be related to more photosynthetically active light. However, the development of shorter stems and heavier roots clearly indicates a morphogenic response to surface color. Although a low FR/R ratio can promote partitioning of relatively more dry matter to the root system (Kasperbauer et al., 1984), the white and black surfaces had very similar FR/R ratios. Thus, the shorter stems and larger roots on plants grown over the white surface cannot be explained by FR/R ratio. Morphogenic responses, however, may have been influenced by the amount of reflected blue light. In laboratory studies, blue light has been found to suppress stem elongation (Thomas, 1981), and Tanada (1984) hypothesized involvement of a light quantity measuring system which he called heliochrome.

Experiment 2

Reflected light spectral patterns over white, brick-red, and near-black soils were similar to those obtained over the painted panels, as well as to those reported for similar soils by Kasperbauer and Hunt (1987). As in the previously reported study, soil covered with straw residue reflected more light than black soil and less light than white soil. The FR/R ratios were similar for white, red, and black soils but higher for the residue-covered soils. Percentage of blue light reflected (relative to that of incoming sunlight) was highest over the white soil.

As with plants grown over painted surfaces in Exp. 1, those grown with the white soil had shorter stems and more lateral roots than those grown with bare black soil (Table 3). Plant growth responses with the straw mulch provided evidence that more than one photomorphogenic pigment system may be involved. The slightly higher FR/R ratio could have contributed to partitioning of more photosynthate to the stem and a higher shoot:root dry matter ratio. Plant growth responses to FR/R ratio differences as small as 0.05 during the photosynthetic period have been reported (Andersen et al., 1985). Stem length differences, however, also occurred between plants grown with white and black soils that had very similar FR/R ratios, suggesting that a response to amount of reflected blue light might be involved. Therefore, Exp. 3 was designed to compare plant growth over surfaces that reflected the same amount of photosynthetic light and had the same FR/R ratio but very different amounts of reflected blue light.

Table 4. Characteristics of soybean seedlings and upwardly reflected light over surfaces that reflected the same PPFD and FR/R ratios but different amounts of blue (400–500 nm) light.

Characteristic	Reflected blue light: Low	High	Significance*
Soybean seedlings			
Stem length, mm	106	99	*
Root wt, mg/plant	125	138	*
Nodule wt, mg/plant	11	18	*
Upwardly reflected light 10 cm above surface			
PPFD μmol m $^{-2}$s $^{-1}$†	345	365	NS
FR/R photon ratio	0.89	0.87	NS
Blue (% of incident blue)	14	74	*

* Indicates means differ at P = 0.05 by paried comparisons.
† PPFD = photosynthetic photon flux density, and FR/R = ratio of photons received at 735 nm divided by photons received at 645 nm.

Experiment 3

As predicted by results of the two previous experiments (Tables 2 and 3), plants grown over the surface with high blue reflection had shorter stems, heavier roots, and greater nodule weight (Table 4) than plants grown over the surface with low blue reflection. The data clearly show that the relative amount of blue light received by a growing plant can influence its development, including nodulation. Although not yet identified, the blue light receptor could be the hypothesized heliochrome discussed by Tanada (1984), or it could be associated with the relatively weak absorption of blue light by phytochrome (Kasperbauer et al., 1964).

CONCLUSIONS

1. Soybean seedlings were significantly altered by light reflected from variously colored surfaces, even though root temperatures, moisture, and nutrition were not significantly different for the different surface color treatments.
2. The measured growth characteristics were responsive to different aspects of reflected light, which included total quantity, blue enrichment, and FR/R ratios.
3. The quantity and spectral distribution of reflected light for optimal plant growth and yield in a particular environment might differ with crop and management practices. Thus, a better understanding of the effects of surface color on plant establishment, growth, and productivity is needed.

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