Cotton Seedling Root Growth Responses to Light Reflected to the Shoots from Straw-Covered versus Bare Soil

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ABSTRACT

Poor seedling establishment can severely impact cotton (*Gossypium hirsutum* L.) when grown in a double-crop sequence following wheat (*Triticum aestivum* L.). My objective was to determine whether the light spectrum reflected from wheat straw to the cotton seedlings could be a contributing factor. Cotton was planted in 3 L pots of loamy sand which was screened to remove old plant residue. Pots were arranged in groups of five and covered with 122- by 122- by 2- cm polystyrene foam insulation panels which had 5-cm holes centered over each pot. Panels were covered with fresh wheat straw, weathered straw, or bare soil so that different far-red to red (FR/R) light ratios were reflected. Insulation maintained the same soil temperature (±0.5) in all pots regardless of surface cover. Each pot was thinned to a single seedling that emerged on the same day. Leaf area and stem length were measured on seedlings cut at the soil surface 1 wk after emergence. Roots were washed free of soil, spread on paper, covered with transparent plastic, and photocopied. Root lengths were measured on the photocopies. Stems, leaves, and roots from each plant were dried and weighed. The fresh wheat straw reflected the highest FR/R ratio and resulted in seedlings with the least root length, lowest root weight, longest stems, and lowest root/shoot weight ratio. This 2-yr glasshouse study shows that the spectral environment over fresh straw can contribute to modified seedling morphology and suggests that it should be considered when developing management practices for no-till double-crop cotton.

EARLY ROOT DEVELOPMENT is important for seedling establishment, especially if available soil moisture is marginal. This can be critical for cotton when it is double-cropped after wheat harvest because the number of remaining freeze-free growing days is limited.

Double-crop studies on the southeastern Coastal Plain of the USA have shown that stand establishment (plant population density) and yield of the second crop can be influenced by the presence or absence of straw or other plant residue left on the soil surface (3, 19). Several contributing factors have been suggested. For example, the dead plant residue can affect soil to seed contact (9), disease buildup, soil temperature (6), and allelopathic effects (7). Another possible contributing factor is that dead plant residue on the soil surface can alter the color of light reflected to young seedlings (15). This should be considered because color of light can affect photosynthate allocation within seedlings (12, 13). Among these factors, the least is known regarding the effects of light reflected from fresh straw during early seedling growth. More information is needed on effects of light reflected from straw while experimentally minimizing other effects of straw residue on germination and early growth of cotton seedlings.

The spectral environment to which seedlings are exposed is important because the FR/R photon ratio received by a growing plant can regulate photoassimilate allocation and affect relative size of roots and shoots (10). A higher FR/R ratio results in partitioning more photoassimilate to stem growth, leaving less for new root growth. In the field, plant growth is highly responsive to the amount of FR reflected from nearby plants (1, 11, 16, 17). The reflected FR affects the FR/R ratio, which acts through the phytochrome system within the growing plant and regulates morphological adaptation to population density (17, 18). Phytochrome in a growing plant responds essentially the same whether the FR/R enters a leaf from the upper or from the lower surface (13). Hence, the amount and color or condition of straw on the soil surface may be important to the reflected light, early root development, and seedling establishment when cotton is double-cropped following wheat harvest. The objective of this study was to evaluate effects of fresh versus weathered straw and bare soil on the reflected light environment, and on root and shoot growth of cotton seedlings exposed to this light during the first week after emergence.

MATERIALS AND METHODS

Plant Material and Growth Conditions

Cotton (cv. 'PD-1') seedlings were grown in 3-L pots of Norfolk loamy sand (Typic Kandiudults) in a glasshouse with natural photoperiods near Florence, SC, in 1994 and 1995. The experiments were done in late June each year because that is the time of wheat harvest when straw is frequently left on the soil surface, and cotton is sown as the second crop in a double-crop conservation tillage system in southeastern USA. The soil was taken from fertilized field plots, passed through a 2-mm screen to remove old roots and debris, and thoroughly mixed before filling the pots. The old roots and debris were removed from the soil to avoid their inclusion during measurement of new roots. Pots were arranged in groups of five on each of two benches each year. A polystyrene foam panel (122 by 122 by 2 cm) with five 5-cm holes was placed over each group of five pots. Several seeds were sown through each hole onto the surface of the moistened soil and covered with 2 cm of moist soil (to bring the soil level to the upper surface of the panel). Each year, two panels were covered with fresh straw, two with weathered straw, and two with a light-tan

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Abbreviations: FR, far-red light; PPF, photosynthetic photon flux; R, red light.

mixture of local soils (some dry reserves of the weathered straw and the soil mixture used in 1994 were stored in darkness in large plastic bags for use in the 1995 experiment). Seedlings grew from 20 June through 27 June 1994 and from 21 June through 28 June 1995. As seedlings emerged, they were thinned to one per pot by cutting at the soil surface. This procedure allowed evaluation of seedlings that emerged on the same day within each experiment, without disturbing roots of the remaining seedling. Below-ground remnants of the cut-off seedlings were removed during the washing of soil from the roots of the remaining seedling in each pot at the end of the growth period.

Reflected Light and Soil Temperature

Upwardly reflected light was measured 10 cm above the respective surfaces each year with a LI-COR LI-1800 Spectroradiometer (LI-COR Inc., Lincoln, NE) equipped with a remote hemispherical cosine-corrected light collector on a 1.5-m fiber optic probe. The measurements were taken at solar noon ± 15 min on a clear day before the seedlings emerged. The amount of upwardly reflected photosynthetic light (PPF, 400–700 nm) was expressed as a percentage of incoming sunlight in the same waveband. The R and FR values were measured at 645 ± 5 nm and 735 ± 5 nm, respectively, because these wavebands cover the action peaks for the R-absorbing and the FR-absorbing forms of phytochrome in green plants (14). The values for R and FR in reflected light are expressed as percentages of incoming light at the same wavebands. Values presented are means for at least three scans over each surface in 1994. Those for 1995 were very similar.

The polystyrene foam insulation panels were used to minimize differences in rhizosphere temperature below the different straw or soil surfaces, while allowing different light spectra to be reflected from the straw or soil up to the seedlings. Soil temperatures in pots below insulation panels were monitored at depths of 2.5 cm at 5-min intervals and averaged each hour for 5 d. Temperatures were determined with copper-constantan thermocouples attached to a Campbell CR-7 Datalogger (Campbell Scientific, Logan, UT), as described by Hunt et al. (8). Mean temperature differences in soil under panels with different colored surface materials were less than 0.5°C.

Sampling and Analyses

Plants were sampled 1 wk after emergence. Shoots and roots were separated by cutting at the panel surfaces. Cotyledons and leaves were removed, measured for area on a LI-COR LI-3100 Area Meter, freeze-dried, and weighed on a per plant basis. Stems were measured, freeze-dried, and weighed. Roots were washed by directing a stream of running water into each pot of the loamy sand. Roots from each plant were floated on water and separated into short unbranched segments, placed on a 21.5- by 28-cm sheet of white paper, covered with a transparent plastic page protector, photocopied at actual size, and measured on the photocopies as time permitted (because lateral roots grow so rapidly, practical use of this procedure is limited to the first 6 to 8 d after emergence). After photocopying, the roots were freeze dried and weighed on a per plant basis. Data were analyzed by analysis of variance as outlined by the SAS Institute (20).

RESULTS AND DISCUSSION

Reflected Light

Characteristics of upwardly reflected light measured 10 cm above the straw and soil in 1994 are summarized in Table 1. Values for 1995 were very similar (data not shown). The fresh straw reflected a higher FR/R ratio than the weathered straw; and the soil mixture reflected a lower FR/R ratio than either fresh or weathered straw. The fresh straw clearly differed from the bare soil in the FR/R ratio reflected from the surface to shoots of newly emerged seedlings. However, the quantity of photosynthetic light was very similar over the fresh straw and the soil. This allowed evaluation of cotton seedling response to morphogenic light reflected from fresh wheat straw when total (incoming plus upwardly reflected) photosynthetic light was similar to that over the soil and variability among other factors such as soil temperature were minimized.

Table 1. Characteristics of upwardly reflected light 10 cm above the straw and soil surfaces.

	Surface		
Light character†	Fresh straw	Weathered straw	Soil mixture
Photosynthetic (PPF, 400–700 mm) (%)	26	17	28
Red (R) (%)	28	20	30
Far-red (FR) (%)	40	26	33
FR/R (ratio)	1.42	1.31	1.10

† Measurements were made at solar noon ± 15 min on a clear day before seedling emergence. Values for reflected light are means for at least three scans and are expressed relative to incoming light. The FR/R ratios were calculated before the values for FR and R were rounded off.

Growth Over Straw vs. Bare Soil

Physical size and dry matter distribution among roots, leaves, and stems of cotton seedlings 1 wk after emergence differed among those grown over the fresh straw-covered versus bare soil surfaces (Tables 2 and 3). Although fewer details were recorded in 1994 than in 1995, seedling size and dry matter distribution over three surfaces followed the same patterns each year, indicating the influentual role of reflected morphogenic light during early seedling growth.

In 1994 (Table 2), seedlings grown over fresh straw had less root length per plant and longer stems than those grown over bare soil. In addition to having shorter roots and longer stems, the seedlings grown over fresh straw also had the lowest root/shoot weight and length ratios.

In 1995 (Table 3), seedlings grown over fresh straw

Table 2. Root characteristics and dry matter distribution in cotton seedlings grown in sunlight over fresh straw, weathered straw, and a mixture of soils for 7 d after emergence in June 1994.

	Surface		
Plant character	Fresh straw	Weathered straw	Soil mixture
Roots†			
Length (cm)	272 b‡	297 ab	342 a
Dry wt. (mg)	34 b	35 b	52 a
Shoots			
Stem length (cm)	9.9 a	9.3 a	7.8 b
Shoot dry wt. (mg)	113 a	106 a	105 a
Root/shoot (wt. ratio)	0.29 c	0.34 b	0.49 a
Root/stem (length ratio)	27.4 c	31.9 b	43.8 a

† Include both tap and lateral roots.
‡ Values in the same line followed by different letters differ significantly at $P = 0.05$.

Table 3. Root characteristics and dry matter distribution in cotton seedlings grown in sunlight over fresh straw, weathered straw, and a mixture of soils for 7 d after emergence in June 1995.

Plant character	Surface		
	Fresh straw	Weathered straw	Soil mixture
Roots			
Lateral length (cm)	165 b†	193 ab	206 a
Lateral dry wt. (mg)	19 c	24 b	34 a
Taproot dry wt. (mg)	13 c	16 b	19 a
Total root dry wt. (mg)	32 c	40 b	53 a
Shoots			
Leaf			
Area (cm²)	22.9 a	20.3 b	18.4 c
Dry wt. (mg)	66.3 a	58.3 b	56.1 b
Stem			
Length (cm)	8.3 a	7.9 a	5.1 b
Dry wt. (mg)	27.6 a	26.1 a	16.1 b
Total shoot dry wt. (mg)	93.9 a	84.4 b	72.2 c
Root/shoot (wt. ratio)	0.34 c	0.48 b	0.74 a
Root/stem (length ratio)	20.6 c	25.2 b	41.9 a

† Values in the same line followed by different letters differ significantly at $P = 0.05$.

again had less total root length and longer stems than those grown over bare soil. Dry weights of both lateral and taproots (the uppermost 7 cm in all cases) were lowest in seedlings grown over fresh straw while weights were highest in seedlings grown over bare soil. In addition to taller stems, leaves developed the greatest area over fresh straw. It was evident that cotton seedlings grown in the same volume of the same soil mixture and with the same rhizosphere temperature had significantly different root and shoot growth patterns between those grown for the first week after emergence over fresh straw versus bare soil. Morphological responses of seedlings grown over the weathered straw were numerically between those of seedlings grown over fresh straw versus bare soil in both years of the study.

Within each year, seedlings grown in sunlight over fresh straw or bare soil received similar amounts of total (incoming plus reflected) photosynthetic light and different reflected FR/R photon ratios (see Table 1). This is important during seedling establishment because the FR/R ratio plays a major role in regulating allocation and use of the new photosynthate in developing roots, stem, and leaves (2, 4, 10, 16). In nature, seedlings are extremely responsive to the FR/R ratio as a sensor of competition from other plants and a regulator of growth to favor adaptation and survival among the competing plants (1, 11, 12). They sense a higher FR/R ratio as an indication that other plants are nearby (competing green plants absorb much of the incoming R while reflecting much of the FR). The adaptive response to a higher FR/R ratio is allocation of more photoassimilate for growth of longer stems (to outgrow the competing plants) leaving less for new root growth, which can result in a decreased root/shoot biomass ratio. Even though the adaptive morphological response to the FR/R ratio very likely evolved in response to the amount of competition from living plants, seedlings also respond to the FR/R ratio if varied through use of artificial light sources and filters in controlled environments (5, 10) or by reflection from different colored soils, artificial mulches, or plant residue on the soil surface (15).

For the FR/R ratio reflected from fresh straw or from any other surface to be effective in photomorphogenesis, the R and FR photons must enter the plant tissue where they function through the natural phytochrome system within developing parts of the plant. The ratio affects the photoequilibrium between the R-absorbing and the FR-absorbing forms of phytochrome which affects allocation of new growth among developing parts of the plant (13, 14). In the present study, several factors may have contributed to the differences in morphological responses of cotton seedlings to what may appear to be a relatively small difference in FR/R ratio reflected from fresh straw versus bare soil (Table 1). For example, green seedlings contain much higher concentrations of chlorophyll than phytochrome. This is important because it contributes to an apparent magnifying effect on the FR/R ratio within the seedling tissue. The R photons that enter the tissue meet competitive absorption by chlorophyll at 660 nm, which is the absorption peak for the R-absorbing form of phytochrome. This competitive absorption at 660 nm shifts the action peak for the R-absorbing form of phytochrome to about 645 nm where it is considerably less efficient (14). On the other hand, FR photons that enter the tissue meet little competitive absorption beyond about 735 nm, and even less beyond about 745 nm. In a highly relevant study by Vogelmann and Bjorn (21), fiber optic probes were inserted into fleshy leaves and the measured FR values at 750 nm within the tissue were higher than those measured at the exterior surface of the leaf where the light entered. They attributed the increased FR values measured within the leaf tissue to photon scattering, internal reflection, and little competitive absorption at 750 nm within the tissue. Although 750 nm is beyond the absorption peak for the FR-absorbing form of phytochrome in vitro and was generally ignored in early studies of R-FR photoreversible control, it is the approximate beginning of the FR reflection plateau from green leaves (11). Another relevant observation occurred in 1962 when I found that FR at 750 nm was highly effective in stem and leaf morphogenesis in green seedlings that were exposed to narrow wavebands of light on the Beltsville Spectrograph (discussed on p. 825 of a Commentary on Morphogenesis in Green Plants, 13). Thus, the effective FR/R ratio within the young cotton seedlings with leaf-like cotyledons (which are fleshier than the true leaves that develop later) was hypothesized to be greater than the ratio at the point of entry on the surface of the cotyledons. The geometry of the cylindrical hypocotyls might also contribute to internal light scattering and/or reflection of FR photons which could magnify the effective FR/R ratio, affect the photoequilibrium between the R-absorbing and FR-absorbing forms of phytochrome in the young stem tissue, and result in different morphological characteristics. This hypothesized scenario provides a possible explanation for development of the significantly different morphological responses of cotton seedlings during the first week of growth over fresh straw versus bare soil.

In summary, the fresh straw reflected a higher FR/R photon ratio than the bare soil. Morphology of cotton seedlings differed significantly between those grown in sunlight over fresh wheat straw and bare soil during the first week after emergence. The larger shoots with larger leaf areas and smaller root systems on seedlings grown over fresh straw could increase the evaporative demand and increase the probability of drought stress if soil moisture was deficient during the first days after emergence. Finally, cotton seedlings were morphologically very responsive to reflection from the fresh wheat straw, which suggests that this growth regulatory factor should be considered when developing a management system for double-crop cotton following wheat.

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