Agricultural and Forest Meteorology 184 (2014) 170–178

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

# Solar ultraviolet radiation exclusion increases soybean internode lengths and plant height

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ARTICLE INFO

*Article history:*
Received 13 September 2012
Received in revised form
26 September 2013
Accepted 28 September 2013

*Keywords:*
Greenhouse spectral transmission
Internode elongation
Soybean
Ultraviolet (UV) radiation

ABSTRACT

Soybean [*Glycine max* (L.) Merr.] cultivars Williams-82 and Maverick were grown in a polycarbonate greenhouse (P-GH), a glass greenhouse (G-GH), and outdoors during daytime (control) to investigate the effect of (i) exclusion of both ultraviolet B (UV-B, 280–320 nm) and ultraviolet A (UV-A, 320–400 nm), (ii) exclusion of UV-B only, and (iii) exposure to daytime solar UV radiation (09:00–17:00 h local time daily). Both the P-GH and the G-GH were maintained at day/night air temperatures of 30/22 °C. The purpose was to quantify the growth differences due to partial and total UV exclusion compared with the control. Exclusion of both UV-B and UV-A radiation caused elongated internodes on the plants, which resulted in greater plant height. Mean mainstem length of Williams-82 was 50.2 cm for the control, but they were 45% and 237% greater for excluded UV-B radiation only and both excluded UV-B and UV-A radiation, respectively. Similarly, mean mainstem length of Maverick was 55.2 cm for the control, but they were 52% and 198% greater for excluded UV-B only and both excluded UV-B and UV-A, respectively. There also was a slight increase in the number of nodes with increasing extent of UV radiation exclusion. The mean final V-stage of Williams-82 was 14.2 for the control, but they were 11% and 18% greater for excluded UV-B only and both excluded UV-B and UV-A, respectively. Likewise, the mean final V-stage of Maverick was 14.5 for the control, but they were 12% and 22% greater for excluded UV-B only and both excluded UV-B and UV-A, respectively. With exclusion of both UV-B and UV-A, pod yield for the Maverick cultivar was greater but this effect was not as clear for the Williams-82 cultivar. In summary, most of the total UV-exclusion effects were due to the exclusion of the UV-A radiation component. Finally, UV spectral transmission of greenhouse or controlled environment covering material should be considered before conducting research on plants, or producing plants commercially, that are sensitive to UV exclusion, such as certain grain legumes or horticultural crops.

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## 1. Introduction

During the 1970s to 1990s, many studies were conducted on the exposure of plants to elevated levels of ultraviolet-B (UV-B, 280–320 nm) radiation (e.g., Caldwell, 1971; Krizek et al., 1976; Biggs et al., 1981; Vu et al., 1984; Teramura et al., 1991; Runeckles and Krupa, 1994). Interest in the damaging effects of UV-B radiation continues (e.g., Krizek, 2004; Dehariya et al., 2012; Kataria and Guruprasad, 2012; Klem et al., 2012; Schreiner et al., 2012; Singh et al., 2012).

Little interest has been shown in studying the effects of UV radiation exclusion (UV-B or UV-A) on plant growth and development, although many greenhouse, hoophouse, or growth chamber cladding materials exclude at least some of these wavelengths (Krizek et al., 2005). In 2011, we discovered that soybean (*Glycine max* L. Merr., cv. Maverick) grew excessively long internodes in a new polycarbonate greenhouse (P-GH), constructed with Lexan™ Thermoclear™ Plus 2UV Sheet, Sabic Innovative Plastics™, Product Datasheet, 10 mm × 10 mm Twin-wall material LT2UV102RS17. Tests with a broadband radiometer (Erythma UV & UVA Intensity Meter, Model 3D V2.0, Solar Light Company, Inc., Glenside, PA, USA) in clear sky conditions in July 2011 indicated essentially no solar UV radiation was transmitted into this greenhouse.

*Abbreviations:* CER, carbon dioxide exchange rate; DAS, days after sowing; GA, gibberellic acid; G-GH, glass greenhouse; IAA, indol-3 acetic acid, auxin; LAR, leaf area ratio; MG, maturity group; P-GH, polycarbonate greenhouse; PPFD, photosynthetic photon flux density; SLW, specific leaf weight; UV, ultraviolet; UV-A, ultraviolet wavelengths 320–400 nm; UV-B, ultraviolet wavelengths 280–320 nm; UV-B/A, both UV-B and UV-A radiation.

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0168-1923/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.agrformet.2013.09.011

Nijskens et al. (1985) reported transmission of solar radiation from 300 to 2500 nm through a double-wall P-GH and found transmission down to about 380 nm. However, the transmission spectra were obtained at 20 nm steps, and the band-width of the spectrophotometer was not given, which could account for apparent transmission to lower wavelengths than the expected cut-off at about 400 nm. Tuller and Peterson (1988) compared solar transmission through a thin-wall polyethylene material and through a corrugated fiberglass material. Across four wavelength ranges of 300–315, 315–400, 400–700, and 700–1100 nm, they showed that the polyethylene material transmitted 8.3, 41.8, 85.1, and 96.3% of solar radiation, respectively, and the fiberglass material transmitted 0.0, 7.9, 73.0, and 85.1% of solar radiation, respectively. Height of Douglas-fir (*Pseudotsusga menziesii*) seedlings was consistently greater in the "UV-exclusion" fiberglass greenhouse than in the polyethylene greenhouse at common ages of plants.

Several studies of exclusion of UV radiation have been conducted in India (Lingakumar and Kulandaivelu, 1993, 1998; Pal et al., 1997; Lingakumar et al., 1999; Jayakumar et al., 2004; Amudha et al., 2005; Guruprasad et al., 2007). Cowpea *Vigna unguiculata* (L.) Walp. seedlings showed an 18% increase in stem length when grown for 3 days in a growth chamber free of both UV-B and UV-A radiation (Lingakumar and Kulandaivelu, 1993). Lingakumar et al. (1999) found that cowpeas were 40% taller at 15 days after sowing (DAS) in the absence of UV-B. They attributed the UV-B-induced reduction in cowpea stem length to the presumed destruction of endogenous growth hormones (Tevini and Iwanzik, 1986; Tevini and Teramura, 1989).

In a field UV-B exclusion experiment using polyester films covering hut-shaped structures, mung bean *Vigna radiata* (cv. PS-16) height and stem weight was 37% and 55% greater, respectively, at 65 DAS under the UV-B screen (Pal et al., 1997). However, at 80 DAS, they found that maize *Zea mays* L. (cv. SM-600) was affected little. Height of maize was only 5% greater and stem weight was 7% less under UV-B exclusion. These studies indicate that the UV exclusion effect is likely dependent on plant species.

Studies of effects of exclusion of UV-B only and exclusion of both UV-B and UV-A have been conducted in field exclusion chambers. For four cucumber (*Cucumis sativus* L.) cultivars, Krizek et al. (1997) found that, at 19–21 DAS, the average main shoot length was 27% greater for exclusion of UV-B only and 55% greater for exclusion of both UV-B and UV-A. Similarly, the effects of these exclusions on guar bean (*Cyamopsis tetragonoloba*), mung bean, and black gram (*Vigna mungo*) were measured by Amudha et al. (2005). They found that, at 50 DAS, guar bean was 21% and 33% taller, and mung bean was 15% and 21% taller, for the exclusion of UV-B only and exclusion of both UV-B and UV-A, respectively. However, there was no difference in the height of the black gram among treatments. Guruprasad et al. (2007) found that height increase of soybean, cv. JS7105, was 30% for UV-B exclusion and 60% for both UV-B and UV-A exclusion of solar radiation. At 70 days after emergence, Dehariya et al. (2012) found plant height of cotton (*Gossypium hirsutum* L.) var. Vikram was increased 60% and 112% for UV-B exclusion and both UV-A and UV-B exclusion, respectively. In a study of four cultivars of wheat (*Triticum aestivum* L.), Kataria and Guruprasad (2012) reported maximum height increases at maturity of 20% and 24% for exclusion of those respective UV radiations.

Several studies in controlled environments have used various lamps or filters to investigate the effect of absence of blue, UV-A, and UV-B radiation on plant morphology. Total height of soybean (cv. Williams) was 2.5 times greater for young plants grown under low pressure sodium lamps (deficient in blue, UV-A, and UV-B wavelengths) than for plants grown at the same photosynthetic photon flux density, PPFD (500 $\mu$mol photon $m^2\ s^{-1}$) under broad-spectrum daylight fluorescent lights with a small amount of UV-B radiation between 310 and 320 nm (Britz and Sager, 1990). A similar but smaller total height response (about 1.4 times greater in the high pressure sodium light) was found for young sorghum *Sorghum bicolor* (cv. Rio) plants. Similar increases in soybean (cv. McCall) mainstem length and average internode lengths were reported by Wheeler et al. (1991). At 28 days after planting, mainstem height was 82.2 cm and average internode length was 11.7 cm for plants grown under high pressure sodium lamps that were deficient in blue, UV-A, and UV-B wavelengths. Plant height decreased steadily to about 50 cm with increasing exposure to blue phosphor fluorescent lamps up to a total PPFD of 30 $\mu$mol $m^2\ s^{-1}$ in the 400–500 nm range. Dougher and Bugbee (2001, 2004) and Dougher et al. (2003) defined blue light as wavelengths between 320 and 496 nm, which includes both actual blue light (400–496 nm) and UV-A radiation (320–400 nm). Exclusion of "blue light" with yellow cellulose triacetate Roscolux #312 filters caused elongated internodes with increased cell lengths in soybean and lettuce (Dougher and Bugbee, 2004). Metal halide light had about 26% of PPFD in the 320–496 nm "blue light" wavelengths (Dougher and Bugbee, 2004), which also included an unspecified amount of UV-A radiation.

Absence of blue and UV-A wavelengths made no real difference in stem lengths of young seedlings of a dwarf wheat (cv. USU-Apogee, Dougher and Bugbee, 2001), nor in main culm lengths of another dwarf wheat (cv. USU-Super Dwarf) at 70 DAS (Goins et al., 1997). Elimination of blue wavelengths appears to enhance stem lengths of potato (*Solanum tuberosum*), especially *in vitro* plantlets, although the responses may be inconsistent (Wilson et al., 1993; Yorio et al., 1995; Seabrook and Douglass, 1998). Bell pepper *Capsicum annum* L. (cv. Hungarian Wax) showed increased stem length with blue wavelengths eliminated or reduced (Brown et al., 1995). Cucumber (cv. Hoffmann's Giganta) showed a 4–5 times greater height at 13 days when grown under a lamp that mimicked most of the solar spectrum but had low energy in the blue wavelengths and apparently none in the UV-A (Hogewoning et al., 2010). Except for wheat cv. USU-Super Dwarf, all these experiments reported data on young plants, therefore effects after a long term of plant growth are not known.

Seedling hypocotyl elongation can be affected by exposure to UV radiation. Inhibition of cucumber hypocotyl elongation and hypocotyl curvatures to short term exposures (30 min) have been demonstrated for several wavebands of UV radiation by Shinkle et al. (2004, 2005) and Magerøy et al. (2010). Shinkle et al. (2004) showed that there was both a short term response and a long term response to full-spectrum UV-B (broad band from about 270 nm to about 400 nm), long wavelength UV-B (broad band from about 292 nm to 400 nm), and UV-A (broad band from about 310 nm to about 400 nm). Shinkle et al. (2005) also showed that exposure of cucumber seedlings to narrow-band UV-C radiation (peak about 254 nm) resulted in a reduction of hypocotyl elongation of about 50%. From these experiments, it is clear that exposure of cucumber seedlings to UV radiation for short terms causes a reduction in hypocotyl elongation. By implication, UV exclusion would likely cause increases in hypocotyl elongation.

The studies indicated that plant height was increased by exclusion of UV-B or UV-B plus UV-A in several grain legumes (including soybean, cowpea, mung bean, and guar bean), cotton, wheat, several horticultural crops (including lettuce, potato, bell pepper, and cucumber), Douglas-fir seedlings, and sorghum, but not in maize, dwarf wheat, or black gram. Some of these studies also included exclusion of blue wavelengths (400–500 nm).

The objective of this study was to determine the extent to which exclusion of both UV-B and UV-A radiation and exclusion of UV-B radiation only affects soybean morphological and phenological development with a focus on internode elongation throughout the life cycle. The hypothesis was that exclusion of both UV-B and UV-A would lead to significant, pronounced internode elongation in soybean in comparison to exclusion of UV-B only or exposure to