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Impact of enhanced ultraviolet-B irradiance on cotton growth, development, yield, and qualities under field conditions

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Abstract

The stratospheric ozone depletion and enhanced solar ultraviolet-B (UV-B) irradiance may have adverse impacts on the productivity of agricultural crops. The effect of UV-B enhancements on agricultural crops includes reduction in yield, alteration in species competition, decrease in photosynthetic activity, susceptibility to disease, and changes in structure and pigmentation. Many studies have examined the influence of supplemental UV-B irradiance on different crops, but the effect of UV-B irradiance on cotton (*Gossypium hirsutum* L.) crops has received little attention. Cotton is one of the most versatile of all the crops. It is a major fiber crop of the world and a major source of trade and economy in many countries. In this study, we provide quantitative examination of the effects of elevated UV-B irradiance on cotton plant (Sukang 103). The tested cotton crop was grown under natural and four regimes of supplemental UV-B irradiance in the field. With UV-B irradiance increased 9.5% throughout the growing season, the negative impacts on cotton growth included reductions in height of 14%, in leaf area of 29%, and in total biomass of 34%. Fiber quality was reduced and economic yield dropped 72%; an economic coefficient was reduced 58%. A brief discussion is included on how the impacts on cotton contrast with impacts that have been observed in other studies on other plants, including trees.

Keywords: Ultraviolet-B (UV-B) radiation; Cotton; Yield; Qualities

1. Introduction

One component of global climate change is the loss of stratospheric ozone, which has prompted recent efforts in assessing the potential damage to vegetation due to enhanced levels of ultraviolet-B (UV-B, 280–320 nm) radiation (World Meteorological Organization, 1989; Grant, 1990; Bornman, 1991; Nunez et al., 1994; Caldwell et al., 1998; Madronich et al., 1998). Satellite measurements have shown expansion of stratospheric ozone losses from over the poles of our planet into temperate regions, and ground-level measurements have detected significant UV-B increases (Kerr and McElroy, 1993). Elevated UV-B levels caused by reduced stratospheric ozone are expected to continue well into the 21st century (Madronich et al., 1998; Weatherhead et al., 2000) and many observers expect to see additional evidence of increased ground-level UV-B in mid-latitudes as monitoring networks improve.

Many biological responses to UV exposure are far greater at the shorter wavelengths. Thus, even relatively small increments of UV-B radiation can lead to substantial biological effects (Madronich et al., 1998).

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Though only a small portion of the total solar electromagnetic spectrum, UV-B has a disproportionately large photobiological effect, largely because it is readily absorbed by important macromolecules such as proteins and nucleic acids. In general, plant responses include increased accumulation of flavonoids, increased leaf thickness, increased reflectance of leaves, reductions in growth, and direct damage to photosynthetic mechanisms (Bornman, 1991). Plant species and varieties differ greatly in their response, with the response generally dependent on the ratio of UV-B to UV-A (Teramura, 1983; Tevini and Teramura, 1989; Middleton and Teramura, 1994). Some species show sensitivity to present levels of UV-B irradiance (Bogenrieder and Klein, 1982), while others are apparently unaffected by rather massive UV-B enhancements (Becwar et al., 1982). One-third to one-half of all plant species tested are deleteriously affected by UV-B levels "above ambient" (Sullivan, 1992). A substantial number of studies have been conducted that have evaluated the potential consequences of an increase in UV-B radiation on many plants (Tevini et al., 1981; Teramura et al., 1990; Miller et al., 1994; Caldwell et al., 1998; Correia et al., 1998, 1999; Li et al., 2000, Searles et al., 2001), but we have a rather limited understanding of the role that UV-B radiation plays in controlling cotton growth, development, yield and quality. Searles et al. (2001) searched for "all suitable published studies" with field-based measurements of UV-B influences on vascular plants and found no studies on cotton. The cotton crop is important for natural fiber and is among the main cash crops used in textile, light, food, chemical, medical, and national defense industries. Thus, it is very important to characterize the effects of enhanced UV-B irradiance on cotton plants.

This paper describes field experiments to test the growth and physiological responses of cotton (*Gossypium hirsutum* L.) to enhanced UV-B radiation. The paper provides an assessment of the impact of enhanced UV-B radiation on cotton growth, development, yield, and qualities.

2. Materials and methods

The experimental field was established in the agro-meteorological research station of Nanjing Institute of Meteorology, in Nanjing, China (32.14°N, 118.42°E). A cotton variety, Sukang 103, was evaluated under supplemental UV-B irradiance during the cotton-growing season of 1998. Plants were seeded on Julian day 92, 1998 and were grown in the experimental field with a density of 75,000 plants/ha and the soil fertility at a normal level.

Supplemental UV-B irradiance treatments were applied to three plots of the experimental cotton field through the whole growing season until the harvest. The treatments were two supplemental UV-B treatments, designated as UV_1 and UV_2, and a control treatment described as Ck. The supplemental UV-B treatments UV_1 and UV_2 averaged 4.8 and 9.5%, respectively more UV-B irradiance than the natural UV-B irradiance received by the Ck treatment. Artificial UV-B irradiance was supplied by broadband, "Black-light" lamps with the spectral range of 280–400 nm. Polyester plastic films (0.13 mm-thick Koadcel TA 401) were used to exclude the portion of UV-A (wavelength > 320 nm). The films were changed weekly to ensure uniformity of UV-B transmission. The lamps were oriented perpendicular to the plant rows and suspended above the plants. Lamps were fitted with 50 mm-wide mini-reflectors and manually adjusted for time and height control. Total daily photosynthetic active radiation (400–700 nm) under the lamp fixtures was about 90% of that above the lamps. The lamps were suspended from wires stretched between steel poles at both ends of the planted rows. Supplemental irradiation was provided daily at a constant rate during the day for 8 h centered around the solar noon. For the Ck treatment, lamps were filtered with 0.13 mm thick polyester (spectrally equivalent to Mylar Type S) plastic films that absorb essentially all radiation below 320 nm, so plants beneath these lamps received only natural levels of UV-B. The UV-B irradiance was adjusted monthly to allow for seasonal changes in ambient UV-B. The different UV-B treatments were obtained by varying the distance between the lamps and the top of the plants. The height of the lamps above the plants was adjusted weekly to maintain constant lamp-to-plant distances as the plants grew.

Biological sampling was performed nine times during the growing season in a 1 m^2 area of each tested plot for measuring the height of plant, leaf area, the weight of fresh and dry plants, and changes in chlorophyll content. The net assimilation and relative growth rates were also calculated.

Another three UV-B treatments were designed to test the effect of enhanced UV-B irradiance on cotton qualities. The control treatment was the Ck treatment as described above. The two other supplemental UV-B irradiance treatments, UV_3 and UV_4, were only provided during the critical growing stages that most affect the cotton qualities. UV_3 treatment was applied during the square (flower bud) stage (Julian day 197–216) and UV_4 treatment covered the boll-forming stage (Julian days 223–242). Both UV_3 and UV_4 treatments provided 9.5% more UV-B irradiance than the Ck treatment during the test periods.

In this cotton qualities experiment, samples of the cotton from 10 plants were harvested six times at 5-day intervals from Julian days 258 to 283 for all three treatments. Cotton is a main material for the textile industry. The quality of cotton determines the quality of fabric and price of cotton products. There are many parameters that can be measured to test cotton qualities. They include the cotton types, the gin turnout of unginned cotton, the grade of lint cotton (toughness and maturity of fibers), the length, moisture content and impurities of cotton. International Cotton Trade requires that at least the cotton fiber thinness, toughness and sugar content must be tested to decide the cotton quality. To quantify the effect of enhanced UV-B irradiance on cotton qualities, the following important parameters were examined: M value (the number of μg/in. fiber), P_{si} value (toughness of a bunch of fibers), and sugar content at each harvest.

All data are presented as means of the six samples. For estimating significant differences of the means, a t-test with $\alpha = 0.05$ and 0.01 was performed and presented in tables.

3. Results and discussion

3.1. *Effect of enhanced UV-B radiation on cotton growth*

The cotton plants showed a range of growth responses to supplemental UV-B irradiance during the growing season. Plant height was reduced by supplemental UV-B irradiance (Fig. 1). At the boll-forming stage, plant height under UV_2 treatment was 86% of that under the Ck treatment and the height under UV_1 treatment was 95% of that under the Ck treatment. The reduction of cotton plant height increased with increased UV-B irradiance. The effects of the

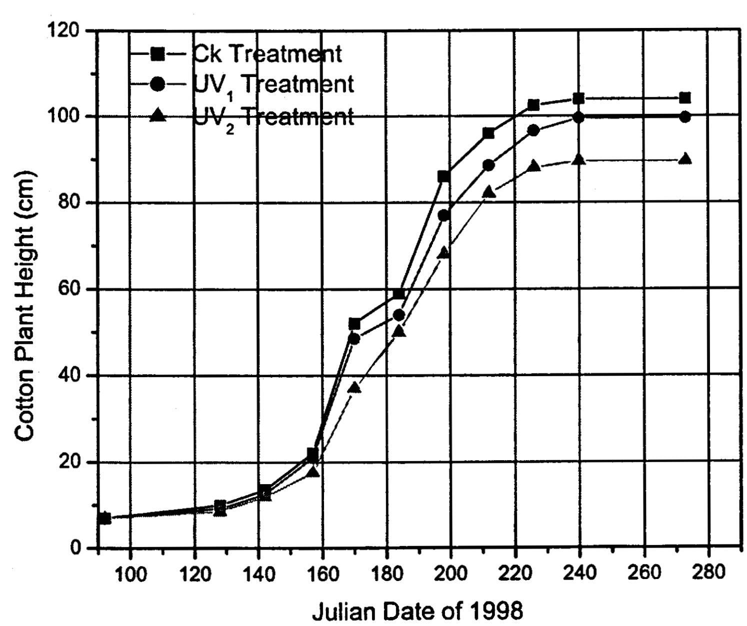

Fig. 1. The change of cotton plant height under different UV-B treatment.

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