5.1 SOYBEAN HELIOTROPISM AND UVB DOSE ESTIMATION

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1. INTRODUCTION

The sensitivity of soybean cultivars to enhanced ultraviolet-B (UVB) irradiance varies widely, with many studies producing contradictory conclusions. For example; Teramura and Murali (1986) found that, out of five cultivars studied, Williams cv. was one of the most UV-sensitive, while Murali et al. (1988) concluded Williams was relatively resistant to UV. Such inconsistencies may in part be due to differences in the radiative environment of the experimental conditions. Some of the variability in reported sensitivity of soybean cultivars appears to correspond to differences in exposure due to heliotropic response (Grant, 1999). The aim of this paper is to further examine the heliotropic movements of the soybean upper trifoliates for three cultivars under greenhouse and field conditions and estimate the UV dose incident on these leaves compared to the commonly-used assumption of exposure is based on horizontal measurements of UV irradiance.

2. METHODS

During the spring and summer of 2001, three cultivars of soybean, Bay, York and Williams 82, were grown in the greenhouse and field at West Lafayette, IN (40.5^{o}N). Measurements of leaf orientation were made using a Microscribe 3D-coordinate digitizing system with a 5^o measurement error. Five points on each leaf of the upper trifoliate were measured, resulting in quadrilateral leaf shapes that can show a bend in the leaf in any direction (Fig. 1), with two additional points along the petiole for the field plants. Three plants of each cultivar were measured in the control group, and four plants each of Williams 82 cv. and York cv., and six plants of Bay cv in the field. Data from each cultivar were averaged into two groups: those with the azimuth of the central leaflet within ±90° of the solar azimuth ("on-sun"), and "off-sun" for the remainder. Only data from clear sky days and "on-sun" measurements will be discussed in this paper due to a low sampling rate in overcast conditions and for the "off-sun" plants.

The UVB exposure of the upper trifoliate was determined using measured UVB irradiance and modeled leaf orientations with the goal of evaluating the relative importance of the varying heliotropic response of the three cultivars to the received dose. Three minute broadband UVB irradiance at West Lafayette (40.5^o N latitude) was measured using a UVB-1 radiometer of Yankee Environmental Systems, Inc. (YES) as part of the USDA UVB Monitoring Program Climatological UVB Network.

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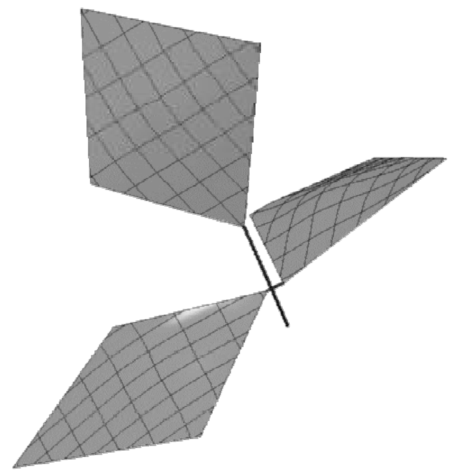

Figure 1 – Constructed tri-foliate leaf based on 3D-coordinate measurements.

The UVB irradiance was partitioned into diffuse and direct beam components using the measured partitioning of 311 nm narrow band irradiance data from a YES UV multi-filter rotating spectral radiometer that is also part of the Climatological UVB Network Station. The exposure was determined from the leaf slope (α) and leaf incidence angles (θ) given the direct beam and diffuse sky radiation and canopy reflectance of 1.5% using the approach outlined in Grant (1999). As in Grant (1999), anisotropic and isotropic sky radiance distribution models were used to determine if the sky radiance distribution, affecting the diffuse irradiance on the leaf, significantly influenced the predicted exposure.

3. RESULTS AND DISCUSSION

The measured heliotropic response was complex and varied between cultivars. On average, the leaflets moved 20 to 40^o per hour over the course of a day while θ varied from 10 to 23^o per hour. Williams 82 cv. had the greatest movement of the three cultivars. The θ of the upper trifoliate of greenhouse and field plants of all cultivars were not significantly different (student's *t*-test, p=0.1) while α was significantly different for the central leaflet of Williams 82 cv. and one side leaflet of Bay cv. Therefore it appears that the plants respond similarly to the movement of the sun in both greenhouse and field.

The extent of variation in the incidence angle on the central leaf of the upper trifoliate for three field plants is shown in Figure 2, with the minimum θ for Bay and Williams 82 occurring late in the day while the minimum θ for York occurred in the late morning. The York cv.

trifoliate tended to turn over by 11AM and turn back over around 2PM (Fig. 2). The variation over the course of the day and between cultivars was much larger than that found by Rosa and Forseth (1995).

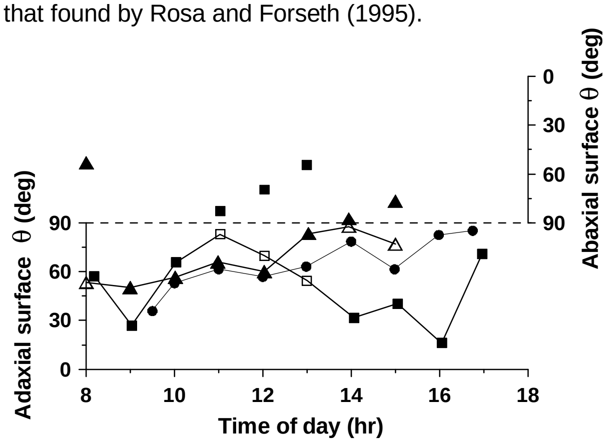

Figure 2 – Diurnal variation in incidence angle (θ) of the top trifoliate center leaflet of Williams 82 (circle), York (square) and Bay (triangle). Filled symbols above the dashed line and mirrored open symbols below the line represent the incidence angles for the abaxial side of the leaf.

The May through August seasonal broadband UVB horizontal exposure was 6.06 MJm^{-2} with 4.68 MJm^{-2} (77%) of the exposure due to the diffuse sky irradiance. In general, the Williams 82 cv., with the largest heliotropic response of the three cultivars, had the greatest exposure to the UVB over the course of the season, receiving 5.79 MJm^{-2}. York cv. received 5.26 MJm^{-2} over the season. Bay cv., with the least heliotropic response, had the lowest estimated exposure to UVB at 5.14 MJm^{-2} over the season. The three cultivars ranged from 84% to 96% of the seasonal exposure based on horizontal plane measurements. Therefore setting enhanced UV levels for UV-effects studies in soybean at say 30% relative to the horizontal irradiance measurement will result in some varieties receiving 25% to 29% enhanced irradiance.

Estimating leaf exposure based on the simpler isotropic assumption of diffuse sky radiance resulted in a UVB exposure that was 8% lower than estimated using previously developed anisotropic sky corrections to the diffuse sky model. Sky conditions influenced the relative exposure of the cultivars; under clear and hazy sky conditions, the exposure of Williams 82 exceeded Bay that exceeded York cv. (morning in Fig 3). Under cloudy skies, the exposure of Williams 82 is less than that of both Bay and York cultivars (afternoon in Fig. 3).

Therefore the relative exposure to the cultivars evaluated would vary by location according to the frequency of cloudy and cloud-free days.

4. SUMMARY AND CONCLUSIONS

Heliotropic movements were complex with leaf movements per hour exceeding solar movement. Williams 82 cv. had the greatest heliotropic response of the three cultivars, resulting in the greatest exposure to UVB under clear and hazy skies. The absence of significant differences in θ between the field and greenhouse plants indicates that the greenhouse environment does not inhibit the heliotropic response of the soybean plants. The larger α values for Williams cv. in the field is reflected in the higher UV dose calculated over the growing season. York and Bay cultivars showed less heliotropic movement and this is reflected in the lower UV doses over the same time period.

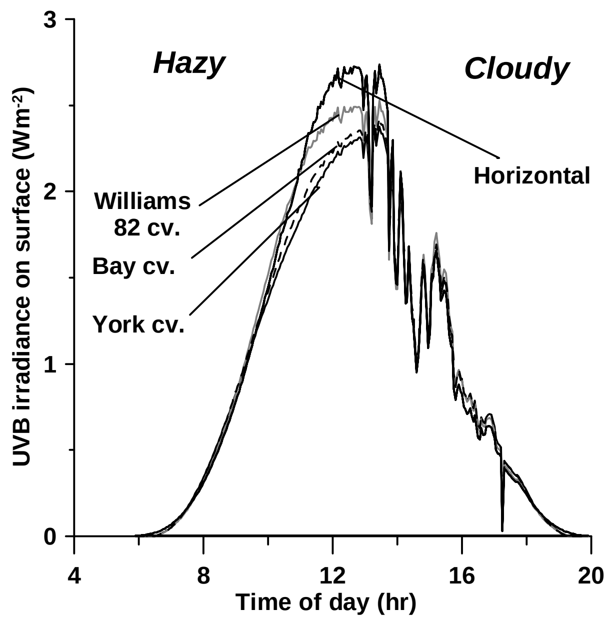

Figure 3 – Irradiance received by three soybean cultivars on a hazy / partly cloudy day.

The heliotropic response is a means of mitigating UVB effects for soybeans. Results suggest that UV-effects research may mis-classify the sensitivity of cultivars to UVB radiation due to the variation in the ability of the cultivars to track the sun, and may mis-rank the sensitivity of cultivars as a result of the proportion of clear to cloudy skies at the research location.

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