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Influence of Soybean Pubescence Type on Radiation Balance[1]

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ABSTRACT

Increasing the density of pubescence on the leaves and stems of soybeans (*Glycine max* L.) should influence the radiation balance of the soybean canopy and affect the evapotranspiration and photosynthetic rates. This study was undertaken to evaluate the influence of increased pubescence density on various components of the radiation balance. Near-isogenic lines of two soybean cultivars (Clark and Harosoy) were grown in four adjacent small plots (18 × 18 m) during the 1980, 1981, and 1982 growing seasons near Mead, Nebr. The soil at this site is classified as a Typic Argiudoll. The isolines of each cultivar varied only in the amount of pubescence (dense vs. normal pubescence). Measurements of albedo, reflected photosynthetically active radiation (PAR), emitted longwave radiation, and net radiation were made over the crop surfaces with instruments mounted on a rotating boom located at the intersection of the four plots. Radiative canopy temperatures were measured with a handheld infrared thermometer (IRT). Results show that dense pubescence increased reflection of shortwave radiation and PAR by 3 to 5% and 8 to 11%, respectively. Emitted longwave radiation and radiative canopy temperature were not significantly affected by increased pubescence, although there was a slight tendency for the dense pubescent canopy to be cooler. Increased pubescence decreased net radiation over the canopy by 0.5 to 1.5%. These results suggest that soybeans with dense pubescence may be slightly better adapted to the high radiation, high temperature, and limited moisture conditions of the eastern Great Plains than are those with normal pubescence.

Additional index words: **Reflectivity, Albedo, Canopy temperature, Net radiation, Near-isogenic lines, *Glycine max* L.**

SOYBEAN [*Glycine max* (L.) Merr.] production is a major component of the American agricultural economy (Probst and Judd, 1973), primarily due to the demand for soybean oil and soybean meal (Kramer, 1973). Soybean production in the USA may be limited by environmental conditions to areas generally east of the eastern Great Plains (Mederski et al., 1973; Probst and Judd, 1973). Soybean production in regions farther west is likely to be limited by high radiation, high temperature, and inadequate soil moisture.

The environment to which plants respond results from the interaction of the atmosphere, the soil and its condition, and the plant's physiological and morphological characteristics. Microclimate can be altered by physical means such as irrigation and windbreaks. It may also be possible to enhance the ability of plants to respond to specific microenvironments by altering plant morphology. Ehleringer and Bjorkman (1978a) and Ehleringer and Mooney (1978) have shown, for example, that pubescence (plant hairs) is an adaptive feature of plant morphology which is found in plants naturally occurring in high radiation, high temperature, and low moisture environments. We reasoned that increasing the density of pubescence on soybean leaves and stems might create more favorable conditions for soybean production in subhumid and semiarid regions. This study was designed to test that hypothesis.

In most literature dealing with the effects of increased plant pubescence, components of the radiation balance from individual leaves have been measured. The results of such studies are inconsistent. Gausman and Cardenas (1969, 1973) found that increased pubescence slightly decreased the reflectivity of near infrared radiation (NIR), but had no effect on the reflectivity of photosynthetically active radiation (PAR) in leaves of *Gynura aurantiaca* and soybeans. Billings and Morris (1951) found that increased pubescence on the leaves of four different plant species increased the reflectivity of both PAR and NIR. Ehleringer et al. (1976) reported that leaves of the densely pubescence desert shrub *Encilia farinosa* reduced the absorption of PAR by as much as 56% of that absorbed by a

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closely related but nonpubescent species, *E. californica*. Ehleringer and Bjorkman (1978a) found that as pubescence density increased on plants of *E. farinosa* subjected to differing environmental conditions the reflectivity of both PAR and NIR increased, but that the pubescence acted as a more effective reflector of NIR than of PAR. Ehleringer and Mooney (1978) also reported that as pubescence density increased in *E. farinosa* leaf absorptance of incident radiation was reduced. This resulted in a reduced heat load, lower leaf temperatures, and lower transpiration rates. Ehleringer and Bjorkman (1978b) reported that decreasing PAR absorption was the primary reason causing lower photosynthetic rates in leaves of *E. farinosa* with increased pubescence density. Conversely, Ghorashy et al. (1971) and Nielsen et al. (1984) found that increased pubescence had no effect on the photosynthetic rates of soybean leaves. Baldocchi et al. (1983b) found pubescence density did not alter photosynthetic rates of soybean canopies.

An increase in shortwave reflectivity induced by greater pubescence should be beneficial to C_3 species such as soybeans in which the outer canopy leaves light saturate. These light-saturated leaves on the canopy periphery are responsible for about 90% of the total radiation intercepted by a soybean canopy (Sakamoto and Shaw, 1967). Hence, any resulting reduction in net radiation due to increased pubescence should decrease leaf temperature and evapotranspiration but should not greatly affect total canopy photosynthesis.

In a companion study to the one reported here, Baldocchi et al. (1983a) reported that increased pubescence in soybeans altered the surrounding microenvironment by facilitating the penetration of net radiation into the canopy. Baldocchi et al. (1983b) also noted that changes in the microclimate of the soybean canopy due to increased pubescence improved water use efficiency by reducing evapotranspiration. They theorized that the increased net radiation at lower levels in the soybean canopy did not increase the latent heat exchange because the vegetative evaporative surface area is sparse and stomatal resistance is greater in the lower canopy. The present study was part of an overall experiment investigating the physiological, agronomic and micrometeorological responses of near-isogenic soybean isolines varying in pubescence density (Baldocchi, 1982; Clawson, 1983; Nielsen, 1983).

MATERIALS AND METHODS

Near-isogenic lines of the soybean cvs. Clark and Harosoy differing in pubescence density were planted in adjacent plots (18 × 18 m) during the 1980 growing season at the Univ. of Nebraska Agricultural Meteorology Laboratory near Mead, NE (41°09'N96°39'W; 354 m above mean sea level). In 1981 and 1982, only the Harosoy isoline was grown. The isolines of each cultivar differed in a gene controlling pubescence density. The number of hairs on the leaves of the dense pubescence isolines was approximately four times that on leaves of the normal pubescent plants. Singh et al. (1971) reported pubescence densities for the isolines used in this study as 8.1, 31.0, 6.1, and 29.7 hairs/mm^2 for the Harosoy normal, Harosoy dense, Clark normal, and Clark dense isolines, respectively. The pubescence of the Clark isolines was tawny (brown) and that of the Harosoy isolines was light grey. The soil at Mead is a Typic Argiudoll (Sharpsburg silty clay loam). The isolines were planted in north-south rows with a row spacing of 0.76 m in 1980 and 0.51 m in 1981 and 1982. Final plant population was about 390000 plants/ha in all years. Seasonal water use was measured by monitoring soil moisture by the neutron scattering technique. Final seed yields were measured.

We expected that any differences in components of the radiation balance would be small since there was little difference in the visual appearance of the isolines varying in pubescence. To minimize error in the measurement of these small differences, a single set of instruments was mounted on a rotating instrument boom placed at the common corner of four adjacent plots. The instruments were mounted at the end of the boom arm, approximately 6 m from the axis of rotation (Fig. 1). The arm was raised periodically to maintain a height of about 1 m between the sensors and the top of the crop canopy. This ensured that about 95% of the area viewed by the instruments was within the borders of the plot (Reifsnyder, 1967).

The components of the radiation balance are given as:

$$R_n = SW\downarrow + LW\downarrow - SW\uparrow - LW\uparrow,$$

where

R_n = net radiation,
$SW\downarrow$ = incoming shortwave radiation (0.3–4.0 μm),
$LW\downarrow$ = incoming longwave radiation (4.0–50 μm),
$SW\uparrow$ = outgoing (reflected) shortwave radiation, and
$LW\uparrow$ = outgoing (reflected and emitted) longwave radiation.

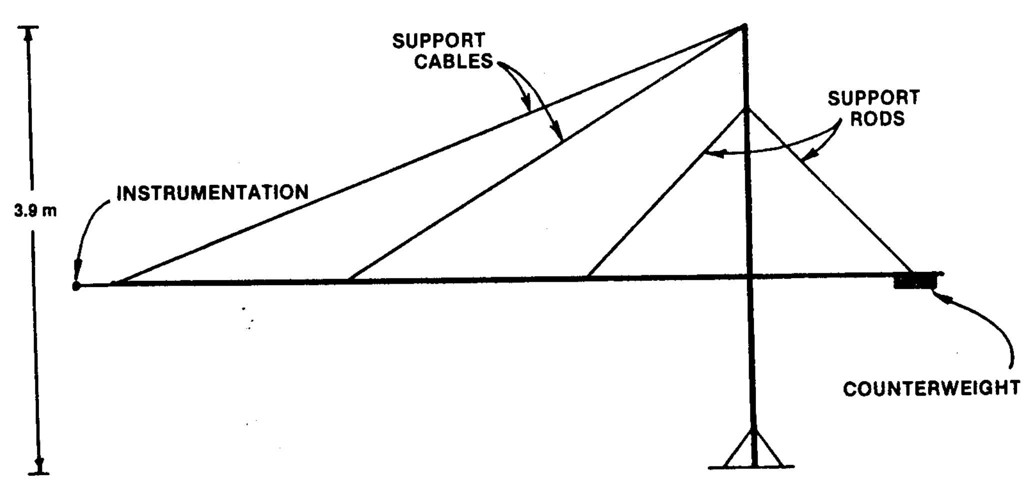

Fig. 1. Schematic representation of rotating boom used to move radiation balance instrumentation over adjacent plots.

Table 1. Results of paired-t statistical analysis comparing components of the radiation balance over canopies of dense and normal pubescent isolines of Clark and Harosoy soybeans.

		R_n†	SW↑	PAR↑	LW_{em}
1980	n‡	51	57	56	52
Clark	mean diff.	+2.13 W m⁻²	−1.19 W m⁻²	−4.46 μE m⁻² s⁻¹	+1.06 W m⁻²
	t_{paired}	1.81	3.08**	10.7**	1.46
1980	n	34	49	53	37
Harosoy	mean diff.	−4.12 W m⁻²	−1.68 W m⁻²	−4.15 μE m⁻² s⁻¹	−1.51 W m⁻²
	t_{paired}	4.09**	4.06**	13.8**	1.88
1981	n	25	25	18	25
Harosoy	mean diff.	+5.44 W m⁻²	−2.72 W m⁻²	−3.89 μE m⁻² s⁻¹	−2.64 W m⁻²
	t_{paired}	5.23**	9.15**	5.43**	1.35
1982	n	21	21	21	21
Harosoy	mean diff.	+4.62 W m⁻²	−4.29 W m⁻²	−3.69 μE m⁻² s⁻¹	+2.00 W m⁻²
	t_{paired}	4.91**	4.63**	10.00**	4.83**

** Difference between isolines is significant at the 0.01 level.
† R_n = Net radiation, SW↑ = Outgoing (reflected) shortwave radiation, PAR↑ = Outgoing photosynthetically active radiation, and LW_{em} = Longwave emissivity.
‡ n: number of observations, mean diff.: + = normal greater than dense and − = normal less than dense.

R_n was measured with a net radiometer.[3,4] The quantities (SW↓ + LW↓) and (SW↑ + LW↑) were measured with the same type of net radiometers except that the bottom and top polyethylene domes, respectively, were replaced with metal cones blackened on the inside and containing a thermocouple to measure their cavity temperatures. SW↑ was measured with an inverted pyranometer.[5] In addition, reflected PAR was measured with an inverted PAR sensor.[6] Similar sensors to measure SW↓ and incoming PAR were located aproximately 80 m south of the measurement plots. All radiation instruments were calibrated against like instruments held as laboratory standards at the Univ. of Nebraska Center for Agricultural Meteorology and Climatology.

Measurements were made on 5 days between 1 and 21 Aug. 1980, 6 days between 11 and 20 Aug. 1981, and 4 days between 25 Aug. and 3 Sept. 1982. Measurements were made only on days when the sky was clear to ensure that meteorological conditions and plant responses were as close to steady-state as possible. Measurements were made over the same position in each of the four plots twice at the beginning of each hour (solar time). In 1980 and 1981, measurements were made during the first 15 min of each solar hour. An improved data logging system reduced the measurement time to 3 min in 1982. Radiation balance data were averaged over replicated plots to give a single value for the hour for each isoline.

In 1980, it was observed that the boom did not remain level as it was rotated over the various plots. This was corrected in subsequent years by counterweighting the boom. Instrumentation and the boom were checked for levelness three times daily. The major effect of the level problem in 1980 was in the measurement of net radiation. This probably occurred because net radiation includes the direct solar beam while the other measurements are of reflected or emitted diffuse radiation.

Radiative canopy temperature was measured hourly with an infrared thermometer (IRT).[7] Measurements were made by an observer standing on the ground and aiming the IRT at the crop at an angle of inclination of about 15° down from the horizontal. The temperature at the center of each plot was determined as the average of that measured from the north, south, east, and west sides of the plot. For each hour an average temperature was computed for each isoline by combining values from all replicate plots. A paired-t statistical analysis was performed on the radiation balance data. The results of this analysis are given in Table 1.

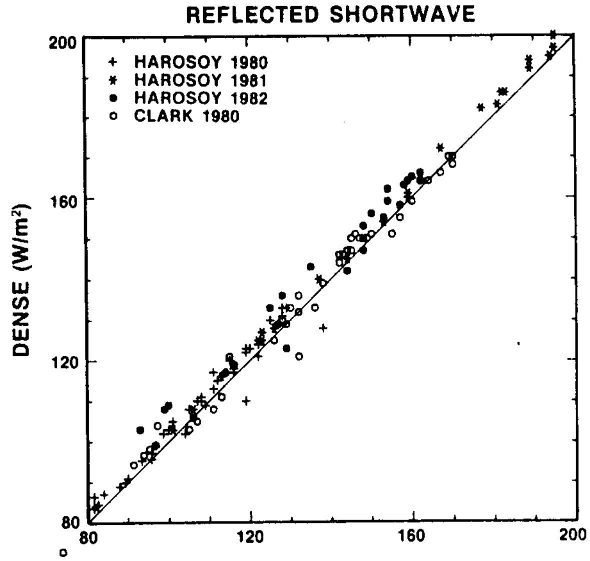

Fig. 2. Comparison of reflected shortwave radiation for dense and normal pubescent isolines of Clark and Harosoy soybeans.

RESULTS AND DISCUSSION

The dense pubescent isolines of both the Harosoy and Clark cultivars reflected more incoming shortwave radiation than did the normal pubescent isolines in each of the 3 years of study (Fig. 2). This increase in reflectivity was statistically significant (Table 1). Paired measurements indicated that midday reflection of shortwave radiation from the dense pubescent isoline exceeded that from the normal isoline by 3–8 W m^{-2}, an increase of 3 to 5%. In 1980, the reflected flux density of shortwave radiation was greater from the Clark than from the Harosoy isolines (Table 1). The planophile structure of the Clark canopy may have been responsible for this effect (the Harosoy canopy exhibits a more erectophile structure). The reflection of shortwave radiation by the Harosoy isolines was

[3] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty for the product by the USDA or the University of Nebraska, and does not imply its approval to the exclusion of other products or vendors that may also be suitable.
[4] Type S-1, Swissteco Pty., Ltd., Melbourne, Australia.
[5] Model PSP, The Eppley Laboratory, Inc., Newport, RI.
[6] Model LI-190S quantum sensor, Lambda Inst., Co., Lincoln, NE.
[7] Model AG-42, Telatemp Corp., Fullerton, CA.

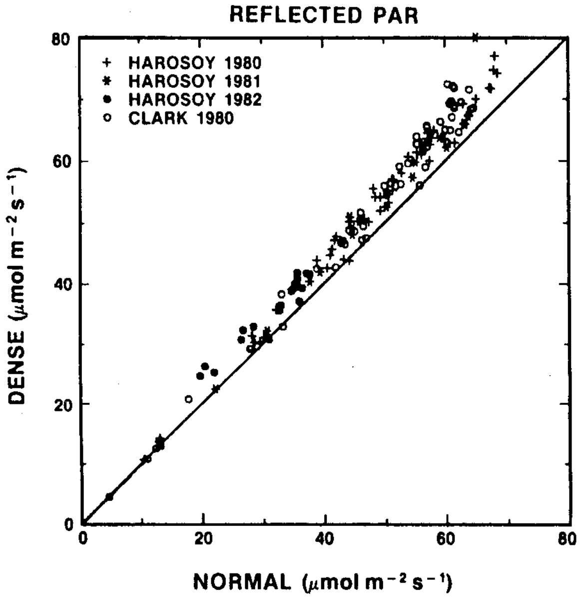

Fig. 3. Comparison of reflected photosynthetically active radiation for dense and normal pubescent isolines of Clark and Harosoy soybeans.

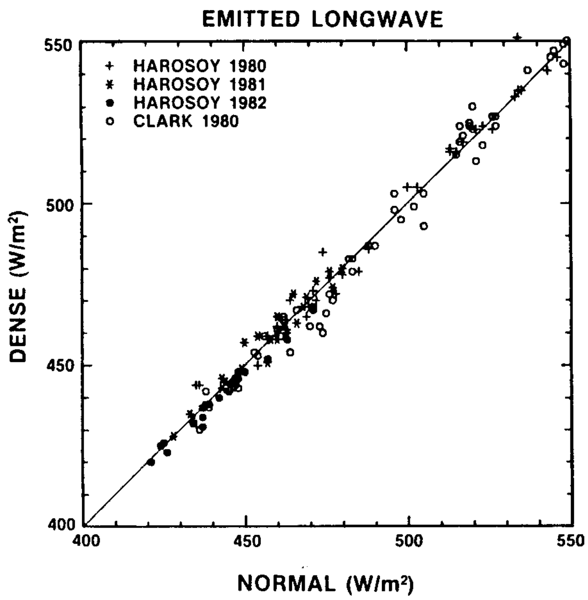

Fig. 4. Comparison of emitted longwave radiation from canopies of dense and normal pubescent isolines of Clark and Harosoy soybeans.

greater in 1981 and 1982 than it was in 1980 (Table 1), probably because of the narrower row spacing and more complete canopy closure in the latter 2 years. The dense isolines also consistently reflected 8 to 11% more PAR than did the normal isolines (Fig. 3).

The measured value of LW↑ is comprised of emitted longwave radiation and reflected longwave radiation. In order to calculate the value of emitted longwave radiation, the longwave reflectivity, r_{LW}, must be specified. This can be computed as

$$r_{LW} = (1 - \epsilon_{LW})$$

where ϵ_{LW} = longwave emissivity.

Emissivity of the Harosoy isoline canopies was measured in 1981 following the method of Fuchs and Tanner (1966). Emissivity of the Harosoy normal isoline was 0.976 ± 0.010, and emissivity of the Harosoy dense isoline was 0.979 ± 0.004. An emissivity of 0.977 was taken as representative of all canopies. Hence, a longwave reflectivity of 0.023 was used in calculation of emitted longwave radiation.

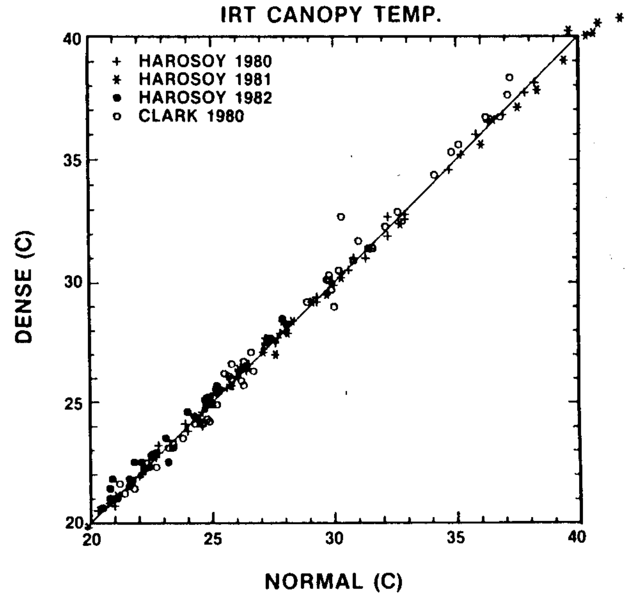

Fig. 5. Comparison of IRT measured canopy temperatures of dense and normal pubescent isolines of Clark and Harosoy soybeans.

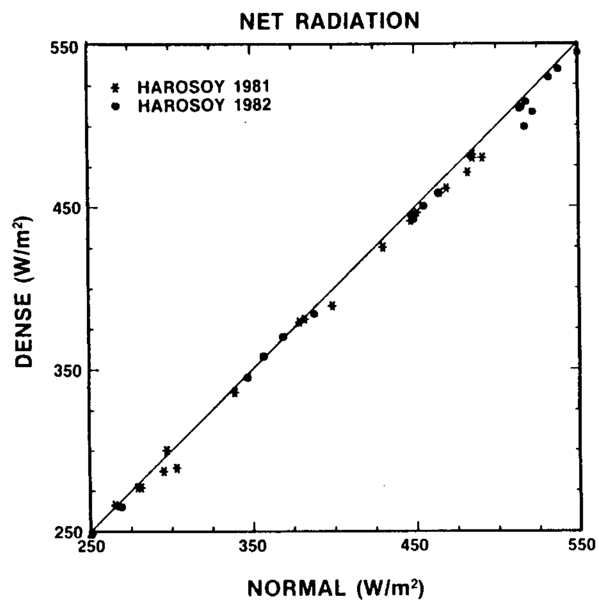

Fig. 6. Comparison of net radiation over dense and normal pubescent isolines of Harosoy soybeans.

Differences in emitted longwave radiation between isolines varying in pubescence were not as clearly defined as in the case of reflected shortwave radiation (Fig. 4 and Table 1). The greater shortwave reflectivity of the dense isolines should reduce energy absorption, thereby reducing the canopy temperature and, consequently, reducing the emittance of longwave radiation; however, no consistent differences between isolines were seen in 1980 and 1981. In 1982, the dense

Table 2. Cumulative evapotranspiration (mm) and seed yield (kg/ha) for soybean isolines differing in pubescence density.

Year	Period of measurement: Dates	Period of measurement: Days after emergence	Cumulative evapotranspiration: Harosoy Normal	Harosoy Dense	Clark Normal	Clark Dense	Seed yield†: Harosoy Normal	Harosoy Dense	Clark Normal	Clark Dense
			mm				kg/ha			
1980	6 June-10 Sept.	10-106	329	318	320	314	2150	2342	2249	2008
1981	1 July-5 Sept.	30-96	216	216	--	--	3037	2841	--	--
1982	13 July-16 Sept.	22-87	231	221	--	--	2960	3136	--	--

† 13% Seed moisture content.

pubescent isoline of Harosoy emitted slightly less longwave radiation.

The comparisons of emitted longwave radiation shown in Fig. 4 should be viewed with caution since the assumption of equal longwave emissivity and equal longwave reflectivity for all isolines may not be valid. Uncertainty in the measured values of emissivity could lead to an error in the computation of emitted longwave radiation as much as 5 W m^{-2}, which was typically the magnitude of the differences observed between the isolines. Differences in canopy temperature between isolines varying in pubescence were essentially nil suggesting little or no effect of pubescence on canopy temperature (Fig. 5).

The net effect of differences in shortwave reflectivity and emitted longwave radiation are seen in the comparison of net radiation (Fig. 6 and Table 1). Net radiation was significantly lower over the dense pubescent isolines of Harosoy in 1981 and 1982, apparently as a result of its greater albedo. Net radiation measurements made in 1980 are suspect due to the previously mentioned instrumentation leveling problem and, therefore, are not shown.

Water use and yield data are shown in Table 2. These data show that seasonal water use was generally slightly less for the dense pubescent isolines. The tabulated yield values for 1980 and 1982 agree with those reported by Hartung et al. (1980), i.e., about 200 kg/ha greater yield in the Harosoy dense isoline than in the Harosoy normal isoline, and somewhat lower yield for the Clark dense isoline than for the Clark normal isoline. These differences are not statistically significant. More detailed water use and yield data for these isolines can be found in Clawson (1983).

SUMMARY AND CONCLUSIONS

The results of this study have shown that dense pubescence significantly increased shortwave reflectivity, particularly in the PAR waveband. The increased shortwave reflectivity had the effect of significantly decreasing the net radiation over the dense isolines. Dense pubescence did not alter canopy temperature significantly, but the normal isoline tended to be slightly warmer than was the dense isoline as indicated by the 1982 emitted longwave radiation data.

Whether statistically significant or not, differences between isolines varying in pubescence density were quite small. Whether such small differences can affect soybean adaptability to areas of production which are subject to high radiation, high temperature, and low moisture remains yet to be determined. Changes in the radiation balance caused by increased pubescence were, however, of the kind suggesting that these plants are morphologically better suited for improved growth and development in semiarid environments. Clearly, our results show that increased pubescence is not detrimental to soybean production in such regions. The worth of such minor morphological changes for increasing or stabilizing yields in stressful environments may be limited; however, the ultimate test of the usefulness of the gene for increased pubescence density will have to await actual yield trials of currently available and future cultivars with and without this gene.

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