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Reflectant Induced Modification of Soybean Canopy Radiation Balance
V. Longwave Radiation Balance

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V. Longwave Radiation Balance¹

Maximo W. Baradas, Blaine L. Blad, and Norman J. Rosenberg²

ABSTRACT

Potential water-savings and increased water use efficiency may result from reflectant-induced modification of the canopy radiation balance. This report is one of a series of papers describing reflectant treatment effects on the radiation balance. The objective of this study was to evaluate the effect of the reflectant treatment on the longwave balance over soybeans [*Glycine max* (L.) Merr.].

Average ratios of the flux densities of net longwave to global radiation on 3 and 9 August, were 0.251, 0.239, 0.257, and 0.241 over 'Amsoy' treated, Amsoy untreated, 'Beeson' treated, and Beeson untreated areas, respectively. Corresponding global radiation reflection coefficients were 0.207, 0.194, 0.235, and 0.211.

The flux density of outgoing longwave radiation was greater from the reflectorized crop than from the untreated crop. This was due both to an increase in the reflection of incoming longwave radiation and to an increase in the flux density of emitted radiation. The increased reflection of longwave radiation was due to a reduction in the longwave absorptivity; the increased emission was caused by the higher temperature of the treated canopy.

The reduction of net radiation over the treated areas resulted from the increased outgoing longwave radiation and from the increased reflection of global radiation. Both processes contributed about equally to the observed differences in the net radiative fluxes between treated and untreated canopies. A mechanism of radiation balance modification by reflectants is proposed to explain the observed changes in net radiation.

Additional index words: Energy balance, Albedo, Short-wave reflection, Evapotranspiration, Stomatal resistance, Canopy temperature, *Glycine max* (L.) Merr.

RELECTANTS have been applied to soybeans [*Glycine max* (L.) Merr.] in order to increase the reflection of incoming solar radiation and decrease net radiation (Doraiswamy and Rosenberg, 1974; Le-meur and Rosenberg, 1976). In a companion paper (Baradas et al. 1976) we have shown that reflectorizing the canopies of two soybean cultivars led to a slight

increase in plant temperature and to a decrease in the long-wave emissivity.

In the study reported here we compare the longwave radiation balance over reflectorized and untreated soybean canopies of two soybean cultivars. One cultivar, 'Beeson,' has a planophile type canopy and the other 'Amsoy,' has an erectophile type canopy. The effects on the longwave balance of the reflectorized canopy which follow from increased canopy temperature and lowered longwave emissivity are evaluated. A mechanism is hypothesized to explain the observed modification in radiation and energy balance caused by the reflectants.

MATERIALS AND METHODS

The experimental design, plot layout, procedure for reflectant application, data analysis, and some of the instrumentation used in this study are described in Baradas et al. (1976). For study of the longwave radiation balance the following measurements were made with instruments mounted on the rotatable arm of a boom (Fig. 1):

- 1) net radiation (measured with Swissteco³ net radiometer, Type S-1),
- 2) incoming longwave radiation (Swissteco net radiometer, Type S-1; lower polyethylene hemisphere replaced with a blackbody cavity), and
- 3) reflected global radiation [inverted Eppley⁴ 10-junction pyranometer fitted with a shield to eliminate multiple reflection inside the glass bulb (Brown et al., 1970)].

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³ Swissteco Pty., Ltd., E. Hawthorn, Vic. 3123, Melbourne, Australia.

⁴ The Eppley Laboratory, Newport, RI 02840.

Fig. 1. Two views of the boom-mounted radiation sensors. A. Swissteco net radiometer; B. Same as A but with black cavity at lower side for measurement of incoming longwave radiation; C. Albedometer; D. Barnes IT-3 IR thermometer; E. ISCO spectroradiometer.

Data produced by a spectroradiometer (seen mounted on the boom in Fig. 1) are not reported in this study. In addition, global radiation was measured at the site with an Eppley pyranometer Model 8-48A.

The radiation sensors mounted on the boom arm were placed about 1 m above the crop canopy. We calculate, by Reifsnnyder's (1967) method, that 50 and 90% of the area seen by the sensors was within a diameter of 2 and 6 m, respectively.

Observations reported here were made on 3 and 9 Aug. 1973, days which were nearly cloudless. The mast was rotated from plot to plot over the reflectorized and untreated Amsoy and Beeson soybeans. A scanning cycle over each plot took about 2 min. to complete. All plots were observed twice hourly.

Stomatal resistance of both soybean cultivars was measured with a diffusion porometer⁵ using the technique of Kanemasu et al. (1969). Measurements were made in 1973 on six leaves in the upper 25 cm of each canopy on plants growing in a large field adjacent to the small plots used in the radiation studies (see Baradas et al., 1976).

Calculation of Outgoing Longwave Radiation. The outgoing longwave radiation ($LW\uparrow$)⁶ is expressed in a radiation balance equation by:

$$LW\uparrow = LW\downarrow + G - \alpha G - R_n \quad [1]$$

where R_n is net radiation, G is global radiation, and αG is reflected global radiation. Radiation away from the surface is indicated by a negative and radiation to the surface by a positive sign. All terms on the right in Eq. [1] were measured directly except for the incoming longwave radiation ($LW\downarrow$).

$LW\downarrow$ was computed from:

$$LW\downarrow = R_t + \sigma(T_c)^4 - G \quad [2]$$

where R_t is the radiation balance measured with a Swissteco net radiometer, the lower polyethylene hemisphere of which was replaced with a black-body cavity. T_c is absolute temperature (K) of the blackbody cavity and σ is the Stefan-Boltzmann constant.

Error Analysis. The magnitude of the maximum possible error in determination of $LW\downarrow$ ($\delta LW\downarrow$) may be obtained by taking the total differential of $LW\downarrow$ of Eq. [2] after substituting the right side of Eq. [2] for $LW\downarrow$. Thus:

$$\delta(LW\downarrow) = \frac{\partial(LW\downarrow)}{\partial(R_t)} \cdot \delta R_t + \frac{\partial(LW\downarrow)}{\partial(T_c)} \cdot \delta(T_c) - \frac{\partial(LW\downarrow)}{\partial(\alpha G)} \cdot \delta(\alpha G) - \frac{\partial(LW\downarrow)}{\partial(R_n)} \cdot \delta(R_n) \quad [3]$$

⁵ Model LI50, Lambda Instruments, 2933 No. 36th St., Lincoln, NE 68504.

⁶ The symbols $LW\uparrow$ and $LW\uparrow$ are used synonymously in this paper; as are $LW\downarrow$ and $LW\downarrow$.

Table 1. Radiation budget over reflectorized and untreated Amsoy and Beeson soybean canopies on 3 and 9 Aug. 1973. (G is global, αG is reflected global; $LW\uparrow$, $LW\downarrow$ are incoming and outgoing longwave; and R_n is net radiation; all values are the daily average flux densities in ly/min).

	G	αG	$LW\downarrow$	$LW\uparrow$	R_n	G	αG	$LW\downarrow$	$LW\uparrow$	R_n
	Amsoy reflectorized					Amsoy untreated				
3 Aug. 1973	1.01	-0.21	0.48	-0.74	0.54	1.00	-0.19	0.47	-0.72	0.56
9 Aug. 1973	1.14	-0.24	0.45	-0.72	0.63	1.14	-0.22	0.44	-0.69	0.67
	Beeson reflectorized					Beeson untreated				
3 Aug. 1973	0.94	-0.21	0.48	-0.73	0.48	0.93	-0.20	0.47	-0.70	0.50
9 Aug. 1973	1.14	-0.28	0.44	-0.72	0.58	1.15	-0.24	0.45	-0.71	0.64

Fig. 2. Global radiation (G), and outgoing longwave radiation ($LW\uparrow$) over treated and untreated Amsoy soybean canopies on 3 Aug. 1973.

After substitution of partial differentials obtained from Eq. [1], Eq. [3] becomes:

$$\delta(LW\uparrow) = \delta(R_t) + 4\sigma(T_c)^3 \cdot \delta(T_c) + \delta(\alpha G) + \delta(R_n) \quad [4]$$

With an accuracy of $0.025 ly min^{-1}$ for R_t and αG , and R_n and $0.25 C$ for T_c then, $\delta(LW\uparrow)$ is approximately $0.08 ly min^{-1}$. Differences in ($LW\uparrow$) between plots of less than $0.08 ly min^{-1}$ would not be significant if different instruments were used for each plot. However, with the same instrument over each plot then measurement errors are due, almost entirely, to the signal resolution possible for each instrument. For R_t , αG and R_n the resolution we achieve is about $0.003 ly min^{-1}$ and for T_c it is $0.25 C$. This gives a maximum error of $0.01 ly min^{-1}$. Thus, with the same instruments used over each plot differences in $LW\uparrow$ greater than about $0.01 ly min^{-1}$ are real.

RESULTS AND DISCUSSION

Outgoing Longwave Radiation

The global radiation (G) indirectly affects the outgoing longwave radiation by increasing surface temperature when G is absorbed by the surface. On the other hand, the reflection of incoming longwave radiation arises from the non blackbody characteristic of the surface and depends directly on the flux density of the incoming longwave radiation.

Daily patterns of $LW\uparrow$ on 3 Aug. 1973 over the Amsoy and Beeson canopies are presented in Fig. 2 and 3, respectively. Except for a short time in the

early morning, $LW\uparrow$ was greater from the treated than from the untreated canopies. Differences were generally 0.03 to 0.04 $ly\ min^{-1}$ in the mid and late afternoon.

Components of the radiation balance on 3 and 9 Aug. 1973 are summarized in Table 1. Values are daily averages of readings taken from 0735 to 1755 hours on 3 August and from 0735 to 1425 on 9 August. Average flux density of net longwave radiation over the treated Amsoy canopy was 0.26 and 0.27 $ly\ min^{-1}$ on 3 and 9 August. Over the treated Beeson canopy (Fig. 3) the values were 0.25 and 0.28 $ly\ min^{-1}$ on these dates. Ratios of the flux density of net longwave to global radiation computed as averages of the two days were 0.251, 0.239, 0.257 and 0.241 for Amsoy reflectorized, Amsoy untreated, Beeson reflectorized, and Beeson untreated, respectively. These results are similar to net longwave radiation measurements made over grass sod and bare soil in Minnesota (Idso et al., 1969). They are also comparable to the net longwave loss of about 23% of global radiation over beans in Belgium reported by Impens and Lemeur (1969).

Flux densities of reflected radiation over the treated canopies on 3 and 9 August were 0.21 and 0.24 $ly\ min^{-1}$ over Amsoy and 0.21 and 0.28 $ly\ min^{-1}$ over Beeson. Shortwave reflection coefficients for Amsoy reflectorized, Amsoy untreated, Beeson reflectorized, and Beeson untreated were 0.209, 0.194, 0.235 and 0.212. The average increase in shortwave reflection due to reflectorizing the soybean canopy has been reported to be from about 10-20% (Doraiswamy and Rosenberg, 1974; and Lemeur and Rosenberg, 1976). For the data reported here the increases due to reflectorizing the canopy are 10% and 5% for the Amsoy and Beeson on 3 August and 9% and 17% for Amsoy and Beeson on 9 August.

Measurements show, as expected, that reflectorizing the canopies caused an increase in the outgoing longwave radiation. The average increase in $LW\uparrow$ was 0.02 and 0.03 $ly\ min^{-1}$ over the Amsoy canopy, 0.03 and 0.01 $ly\ min^{-1}$ over the Beeson canopy on 3 and 9 August, respectively. Baradas et al. (1976) reported that temperature of the reflectorized canopy was often 1 to 3 C higher than of an untreated canopy. The emissivity of the treated crop was reported to be about 0.05 less than that of the untreated crop. These differences in temperature and emissivity would increase the flux density of $LW\uparrow$ from a treated crop by about 0.02-0.05 $ly\ min^{-1}$. Thus the measured increases in $LW\uparrow$ from the reflectorized canopies agree closely with prediction. In general, $LW\uparrow$ was slightly greater over the Amsoy canopy than over the corresponding Beeson canopy, probably because the canopy temperature of the Amsoy was higher than that of the Beeson cultivar.

Mechanism of Soybean Radiation Balance Modification by Reflectants — Hypothesis

A mechanism which may explain the observed increase in canopy temperature, the increase in $LW\uparrow$ and the reduced net radiation over the reflectorized crop is proposed in Fig. 4. The length of the boxes on the "sunset-sunrise-sunset" axis in the figure indi-

Fig. 3. As in Fig. 2 for Beeson cultivar.

Fig. 4. An hypothesis on the mechanism by which reflectants influence the soybean canopy radiation balance.

cates the probable duration of the indicated phenomena.

Fig. 4 shows three direct effects of the reflectant on the treated crop: [A]⁷ increased stomatal resistance; [B] increased reflection of global radiation; and [C] reduced longwave radiation emissivity.

There are three ways by which the reflectant treatment may increase stomatal resistance: (i) by directly plugging the stomates; (ii) by influencing the sensitivity of the guard cell (the reflectant or other ingred-

⁷ The bracketed letters or numbers refer to the labels within the boxes of Fig. 4.

Fig. 5. Stomatal resistance of the upper side of leaves in the top 25 cm of the canopies for treated and untreated Amsoy and Beeson cultivars. The bars indicate standard deviations of stomatal resistance.

ient of the reflectant slurry may interact chemically with the guard cell); and (iii) by reducing the flux density of visible light reaching the chloroplasts of the guard cell, thus affecting the biochemical reactions which control guard cell opening and closing.

It is reasonable to expect an increase in the stomatal resistance of a reflectorized crop since about 30% of the stomates are on the upper side of a soybean leaf (Doraiswamy, 1971, p. 163; Teare and Kanemasu, 1972). Because of windiness at the time of application it is likely that some lower leaf surfaces were also sprayed. Doraiswamy (1971, p. 165) found increased stomatal resistance in soybeans reflectorized with kaolin. We observed a significant increase in the stomatal resistance of the treated Beeson cultivar but no apparent treatment effect in the Amsoy cultivar (Fig. 5). The treatment effect on the Beeson canopy may have been due to differences in the stomatal distribution on the upper side of the leaves of the two cultivars or to multiple applications of reflectant to the Beeson cultivar. Amsoy was treated only once on 28 July while Beeson was treated on 29 July, 8 August, and 17 August.

As discussed earlier in this paper, reflection of global radiation was greater over the reflectorized canopy. This increase in reflected global radiation [B] ranged from about 0.01 to 0.04 ly min⁻¹.

In Baradas et al. (1976) it was reported that reflectorizing the soybean canopy reduced the longwave

radiation emissivity [C] by about 5%. An emissivity of about 0.93 and 0.98 for treated and untreated canopies, respectively, would result in an increase in the flux density of reflected longwave radiation [6] from the treated crop of about 0.02 ly min⁻¹.

A further increase in the outgoing longwave radiation flux [4] would result from increased canopy temperature [3]. This increase in canopy temperature results from a reduction in the crop cooling rate [5] because of the reduced longwave emissivity of the treated crop [C] and from the reduction in transpiration [2] due to increased stomatal resistance [A] and/or the reduced net radiation [1]. The increase (1 to 2 C) in temperature [3] of the treated canopy observed by Baradas et al. (1976) causes an increase in LW↑ [4] of about 0.01 to 0.02 ly min⁻¹.

The total increase in LW↑ in this study ranged from approximately 0.01 to 0.03 ly min⁻¹. This, combined with the 0.01 to 0.04 ly min⁻¹ increase in the flux density of reflected global radiation, produced a reduction in average R_n [4] ranging from about 0.02 to 0.07 ly min⁻¹. The increased reflection of global radiation and the increased LW↑ appear to contribute about equally to the measured differences in R_n . The reduced R_n fluxes reported here are similar to those found by Doraiswamy and Rosenberg (1974) over a kaolin coated Amsoy canopy.

The increase in temperature of the reflectorized crop may seem inconsistent with the observed reduction in R_n . In general, reduced R_n would mean that less energy was available to heat the soil, air, and crop or to evaporate water from the plants. R_n may be partitioned according to the following expression:

$$R_n = LE + A + S \quad [5]$$

where LE is the evaporative flux (latent heat), A is the sensible heat flux to the air and S is the soil heat flux. The reduction in R_n may be accounted for by one or more of the terms on the right hand of equation [5]. Thus, for example, reduction in energy consumed by LE could account for all or most of the reduced energy from R_n .

S is so small in a crop with complete cover that any change in S due to reduced R_n would be negligible. As a result of the increased temperature, A from the treated crop will actually be increased and not reduced. That this is so can be seen from the expression which describes the sensible heat flux from the crop:

$$A = (\rho C_p) (T_a - T_s) / (r_a) \quad [6]$$

where ρ is air density, C_p is the specific heat of air at constant pressure, T_a is air temperature, T_s is surface (crop) temperature, and r_a is boundary layer resistance to the diffusion of sensible heat. The magnitude of A is dependent on the gradient ($T_a - T_s$) so that the warmer the crop the greater the flux of sensible heat from the crop.

Therefore, it appears that essentially all of the reduced R_n would need to be accounted for by a reduction in LE rates. As reported by Baradas et al. (1976) the LE rates of treated Amsoy and Beeson canopies were 9 and 12% lower than from the untreated

crops. This suggests that the measured increase in canopy temperature could have occurred at the same time that R_n was reduced.

The reduced transpiration, in combination with the lower radiation emissivity of the treated crop, caused a temperature difference between canopies which increased during the day. As this temperature difference increased, outgoing longwave radiation from the treated crop also increased relative to the untreated canopy. This in turn, led to reduced net radiation so that a 'cause and effect loop' such as the one depicted in Fig. 4 may have been established.

SUMMARY AND CONCLUSIONS

Outgoing longwave radiation over treated Amsoy and Beeson soybean canopies was increased by about 0.01 to 0.03 ly min⁻¹ after reflectant application. Outgoing longwave radiation appears to have been slightly greater over both treated and untreated canopies of the erectophile Amsoy than over the planophile Beeson cultivar.

The reduction in net radiation over the treated crop was due, about equally, to the increase in reflection of global radiation and to the increase in upward longwave flux. The increase in reflection of incoming longwave radiation, resulting from the reduction in absorptivity of the treated canopy, contributed slightly more to the LW $\uparrow$ flux than did the higher temperature of the treated canopy.

An increase in the temperature of the treated crop at the same time that R_n was reduced was observed. This was possible because reduced LE rates accounted for the smaller amount of energy supplied because of the reduction in R_n .

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LITERATURE CITED

- Baradas, M. W., B. L. Blad, and N. J. Rosenberg. 1976. Reflectant induced modification of soybean canopy radiation balance. IV. Leaf and canopy temperature. *Agron. J.* 68: 843-848.
- Brown, K. W., N. J. Rosenberg, and P. C. Doraiswamy. 1970. Shading inverted pyranometers and measurements of radiation reflected from an alfalfa crop. *Water Resour. Res.* 6:1782-1786.
- Doraiswamy, P. C. 1971. Energy balance and spectral properties of a reflectorized soybean canopy: A preliminary study. *Dep. of Hort. and Forestry, Univ. of Nebraska, Lincoln, Neb. Hort. Progr. Rep.* 88. 189 p.
- , and N. J. Rosenberg. 1974. Reflectant induced modification of soybean canopy radiation balance. I. Preliminary tests with a kaolinite reflectant. *Agron. J.* 66:224-228.
- Idso, S. B., D. G. Baker, and B. L. Blad. 1969. Relations of radiation fluxes over natural surfaces. *Q. J. Roy Meteorol. Soc.* 95:244-257.
- Impens, E., and R. Lemeur. 1969. The radiation balance of several field crops. *Arch. Meteorol. Geophys. Bioklimatol. Ser. B.* 17:261-268.
- Kanemasu, E. T., G. W. Thurtell, and C. B. Tanner. 1969. Design, calibration and field use of a stomatal diffusion porometer. *Plant Physiol.* 44:881-885.
- Lemeur, R., and N. J. Rosenberg. 1976. Reflectant induced modification of soybean [*Glycine max* (L.) Merr.] canopy radiation balance. III. A comparison of the effectiveness of Celite and kaolinite reflectants. *Agron. J.* 68:30-35.
- Reifsnyder, W. E. 1967. Radiation geometry in the measurement and interpretation of radiation balance. *Agric. Meteorol.* 4: 255-265.
- Teare, I. D., and E. T. Kanemasu. 1972. Stomatal-diffusion resistance and water potential of soybean and sorghum leaves. *New. Phytol.* 71:805-810.