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Effect of Increasing Foliage Reflectance on Yield, Growth, and Physiological Behavior of a Dryland Cotton Crop[1]

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ABSTRACT

The effect of kaolin reflectant sprays on the yield, physiological activity, and growth of 'Acala SJ-2' dryland cotton (*Gossypium hirsutum* L.) was studied during 2 successive years in separate field experiments. In the first experiment the treatment increased yield by 12.6%. In the second experiment a significant increase in the number of flowers resulted from the kaolin spray, but subsequent high rates of abscission prevented this spray from producing a significant increase in yield.

The reflectant sprays decreased the rate of $^{14}CO_2$ uptake due to a reduction in light absorption. A reduction in epidermal conductance due to partial physical blockage of the stomata was believed to cause the slower decrease in xylem leaf water potential which followed reflectant treatment. Plant growth, characterized by the stand's height, leaf area index, and dry weight, was not significantly affected.

Additional index words: **Photosynthesis, Stomatal conductance, Xylem water potential, *Gossypium hirsutum* L.**

PREVIOUS work has shown that whitening the foliage of dryland sorghum [*Sorghum bicolor* (L.) Moench] with a kaolin spray increased the grain yield but reduced leaf-area-index, single leaf CO_2 uptake, potential CO_2 uptake, and leaf conductance (Stanhill et al., 1976; Moreshet et al., 1977). Sorghum, as a C_4 plant, has a high optimum temperature for CO_2 uptake and, under field conditions, is not light saturated (Turner and Incoll, 1971). Therefore, it could be postulated that the observed physiological responses to foliage whitening were caused directly by the reduction in solar radiation absorption.

By contrast, C_3 plants such as cotton (*Gossypium hirsutum* L.), are light saturated at relatively low light intensities (Böhning and Burnside, 1956). As a result, in a high radiation environment typical of a rainless, dry summer, the shift of the position on the photosynthetic response curve caused by a reduction of light absorption may result in a minor decrease of potential dry matter productivity.

Reducing radiation absorption may decrease CO_2 uptake indirectly by reducing stomatal opening or by decreasing leaf temperature (Basniski and Evenari, 1974) to a suboptimal level, although Baradas et al. (1976) reported increased leaf temperature of whitened soybean leaf.

Reduced radiation absorption will decrease the amount of energy available for latent heat dissipation. This, combined with the decreased stomatal conductance, would reduce transpiration and allow the treated plant to maintain a higher leaf water potential which may improve productivity.

To test some of these hypotheses, the effect of whitening on the growth, reproduction, and physiological behavior on the typically C_3 cotton crop, was investigated.

MATERIALS AND METHODS

Since the alleviation of moisture stress may become most apparent in drought conditions the experiment was carried out in a dryland cotton crop cultivar, 'Acala SJ-2,' grown in the central and northwestern Lakhish area of Israel during the rainless summers of 1975 (Mivhor Farm, 34°47′E, 31°36′N, 130 m M.S.L.) and 1976 (Kibbutz Negba, 34°41′E Long, 31° 30′N Lat, 85 m M.S.L.). The soils were dark brown grumusolic clay, wetted to a depth of 160 to 180 cm before sowing (30 Mar. 1975 – Mivhor Farm; 11 Apr. 1976 – Kibbutz Negba). The mean annual rainfall is 350 mm at Mivhor and 440 at Negba and the mean Class A pan evaporation during the cotton growing season (April through August) totals 1,150 and 1,050 mm, respectively.

In 1975 the cotton seeds were sown in a paired row pattern with 1 m spacing within the pair and 3 m between pairs. The row orientation was east-west. In 1976 sowing was in uniform 1-m-spaced rows oriented north-south. In both years, plant density was nine to 11/m row length.

The method of preparation of the kaolin suspension was similar to that described by Stanhill et al. (1976) except that 0.3% w/w of sodium hexametaphosphate was added to the

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Table 1. Yields and yield components of a cotton crop sprayed with kaolin in 1975 and 1976.

	1975			1976			
						Gross yield	
	No. of bolls	Wt./boll†	Gross yield	No. of bolls	Wt./boll	Total	From row samples
	m^{-2}	g	kg ha^{-1}	m^{-2}	g	kg ha^{-1}	
Two sprays	29.1	7.08	2,060	29.7	6.13	1,640	1,820
Other treatment‡	28.2	7.06	1,990	28.3	5.86	1,580	1,660
Control	27.2	6.73	1,830	29.2	5.85	1,620	1,710
Significance	N.S.§		*	N.S.	**	N.S.	N.S.

*,** Significant at P = 0.05 and 0.01, respectively.
† Values calculated from gross yield and number of bolls, no statistics applied.
‡ One spray in 1975 and two sprays of local kaolin in 1976.
§ Not significant.

Table 2. Daily integrated effect of kaolin spray on canopy reflectance, $^{14}CO_2$ uptake, stomatal conductance, and leaf xylem water potential during the 1976 cotton growing season. Data are expressed as the percentage ratio between sprayed plot and control check (first spray—22 June; second spray—6 July).

Date of measurement	Reflection	CO_2 uptake	Stomatal conductance	Water potential
	% of control			
20 June	97.5	93.2	97.3	108.5
24 June	117.2	71.6	82.6	100.8
4 July	119.3	86.2	85.5	101.1
15 July	131.5	73.3	69.4	92.4
2 Aug.	113.3	76.1	58.0	89.7

suspension of 25% w/w concentration of fine grade kaolin[3] to improve its dispersion. The spray was applied over the top of the canopy from a standard, tractor-mounted boom sprayer at a rate of approximately 400 liters/ha.

The three treatments tested in 1975 were: (i) Two sprays, one applied 5 to 10 days after the initiation of the first flowers (23 June) and the second in the middle of the flowering period (6 July); (ii) One spray, applied in the middle of the flowering period (6 July); (iii) Untreated control.

The three treatments tested in 1976 were: (i) Two sprays of fine grade kaolin[3] sprayed on 22 June and 6 July; (ii) Two sprays of coarse kaolin[4] with lesser whiteness applied on 22 June and 6 July; (iii) Untreated control.

The treatments were arranged in a randomized block design with four replicates of 32- × 32-m plots in 1975 and seven replicates of 22.5- × 24-m plots in 1976. Yield was harvested from the central 100 m^2 of each plot; i.e., two pairs of rows of 12.5 m length in 1975 and 10 rows of 10 m length in 1976.

Growth Measurements

Growth data were collected in 1976. The height of 20 randomly chosen plants, 10 in the eastern row of the central 100-m^2 area of all plots and 10 in the western row of the same area, were measured on 10 occasions during the growing season. Fresh and dry weight and leaf area of 10 plants were measured on six dates during the growing season, five from each border row of the central 100-m^2 area. Leaves and reproductive organs were separated from the stem and separately weighed, both fresh and oven dry. Leaf area of one of the 10 plants was measured with an area meter[5]. The area of the 10 plants was calculated according to the ratio of leaf area to dry weight. Flowers of 20 m row length per plot were marked and counted on seven dates from 25 June until 2 August in the eastern and western rows of the central 100-m^2 area. The number of marked bolls and their cotton yields were measured separately from the total yield and the percentage of boll retention was calculated.

Physiological Measurements

Diurnal trends of $^{14}CO_2$ uptake were obtained in 1976 using the leaf cup method (Shimshi, 1969; Moreshet et al., 1977). Stomatal diffusion conductance was obtained from a krypton diffusion porometer (Moreshet and Falkenflug, 1978) which measures the sum of the resistances of the stomata in the upper and lower epidermises. The results were expressed as average conductance to water vapor of one surface. The CO_2 uptake and the stomatal conductance were measured in the same leaves, second to fourth from the apex, from five different plants of each treatment. Leaf water potential was measured with a pressure chamber[6] (Scholander et al., 1965). Five leaves per hour, selected as above, were detached and immediately measured.

Solar radiation, reflectance, and air temperature measurements were measured as described in previous publications (Fuchs et al., 1976; Moreshet et al., 1977). The reflectivity (r) and transmissivitiy (t) of the upper surface of three sprayed and three control leaves were measured on an energy per wavelength basis over the 350 to 2,500 nm spectral range with a Beckman DK 2A spectrophotometer having an integrating-sphere reflectance attachment for solid samples. The results were used to calculate leaf absorptivity: $a = 1-(r+t)$.

RESULTS

Yield and Yield Components

The effect on yield of whitening the crop canopy with kaolin is described in Table 1. The 12.6% increase in yield caused by kaolin sprays in 1975 was significant (P = 0.05). Sixty percent of this increase was due to the increase in the number of bolls per unit ground area and the remainder to an increase in the weight per boll. The small increase in total yield of the sampled area (100 m^2) in 1976 was not significant, although a 6.4% increase in yield of the plots sprayed with the fine-grade kaolin was observed in two rows whose flowers were continuously marked. As in the previous year, this increase could be attributed to both increase in average weight per boll and in total number of bolls. The decrease in the yield of the plots sprayed with the local coarse kaolin was significant (Table 1). The cumulative number of flowers during 1976 and the percent fruit set in these two rows are shown in Fig. 1. There was a significant increase (P = 0.01) in the number of flowers in the sprayed plots relative to the control plots after the second spray. The percent fruit set decreased very rapidly with time in both control and treated plots. On 13 July, when the significant increase in the number of flowers was first observed, fruit set was 28 and 19%

[3] Speswhite: Graciously supplied as a free sample by English China Clay Sales Co. Ltd., St. Austell, England, and the local importer, The Mineral Supply for Industry & Agriculture Ltd., Tel Aviv, Israel.
[4] Makhteshim, Be'er Sheva, Israel.
[5] LI-cor Area Meter model LI-3000 and LI-3050A, product of Lambda Instruments Co., USA.
[6] PMS Instrument Company, Corvallis, Oreg.

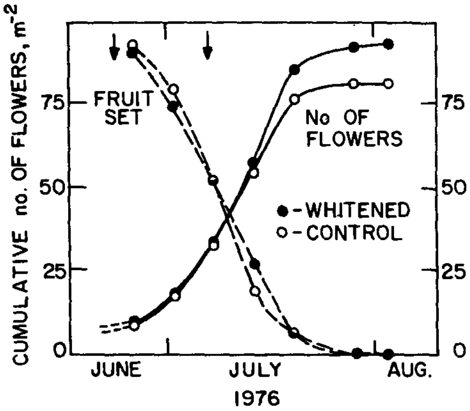

Fig. 1. Effect of kaolin spray on the cumulative number of flowers and the percent of fruit set of a cotton crop (1976). Arrows indicate time of sprays.

for treatment and control, respectively, falling to 5.5% within 6 days. The increase in the number of bolls counted in kaolin-treated plots on 13 July was significant (P = 0.05) as was the higher cotton yield harvested from these bolls (59.2 kg ha^{-1} as compared with 34.7 kg ha^{-1}) from the control (P = 0.01).

Growth

Growth, as characterized by height, LAI, and plant dry weight was not affected by the kaolin spray. LAI, measured at maturity in 1975, was about 40% less than at the end of the growth period of 1976. This difference was attributed to the greater plant density in 1976, when the number of plants per unit area was double that in 1975.

Physical and Physiological Response

The absorptivity of photosynthetic active radiation (PAR) of a single untreated detached cotton leaf averaged 0.87. Solar infrared absorptivity radiation was 0.23 (Fig. 2). Treatment with kaolin spray reduced the absorptivity of PAR to 0.58. In the solar infrared spectrum it increased absorptivity to 0.25, the result of a strong increase in the 710 to 1,500 nm waveband and a slight reduction above 1,500 nm.

The reflection from sprayed crop stand was 17.2% higher than the control after the first spray and 31.5% higher after the second spray, as indicated in Table 2.

Five sets of diurnal curves of canopy reflection, CO_2 uptake, stomatal conductance, and leaf xylem water potential are presented in Fig. 3. Solar flux density in all 5 days was similar, reaching noon maxima between 1,000 and 1,050 Wm^{-2}, with some irregular cloud-induced fluctuations occurring during the mornings of the last 3 days. Air temperature increased from an average of 17 C in morning hours to an average of 30 C at midday. Relative humidity ranged from 80 to 90% in the early mornings to 50 to 60% at midday. The diurnal course of $^{14}CO_2$ uptake before applying the kaolin spray was very similar in the two plots where the measurements were made. Within 2 days after spraying the kaolin reduced $^{14}CO_2$ uptake by more than 20%. This effect was attenuated with time (Fig. 3B and Table 2). Stomatal conductance

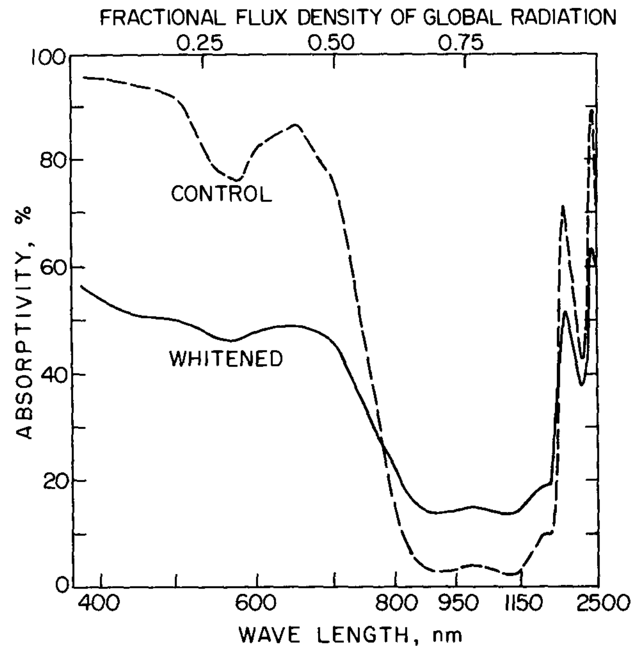

Fig. 2. Absorptivity of kaolin-sprayed and unsprayed cotton leaves sampled immediately after field application (1975). Each line represents the mean of three replicate samples.

also responded immediately to the kaolin application (see Fig. 3C and Table 2).

The xylem water potential response was progressive (Fig. 3D) as can be seen in a comparison of the relative seasonal decrease in water potential of treated and control leaves. The final value of the leaf water potential of the kaolin-treated canopy decreased 19% less than that of the control (Table 2).

DISCUSSION

Whitening the canopy of the cotton crop with kaolin caused a significant 12.6% increase in yield in the 1975 experiment. In 1976 the effect on yield was small and not significant, although the kaolin spray produced a clear effect on the flowering. From the date of the second spray the number of flowers in the treated plots was significantly higher than in the control plots. An influence of the spray on the formation of a larger number of meristematic flowering sites must be ruled out because the kaolin was only applied 21 days before the first significant difference in number of flowers was recorded on 13 July, a much shorter time than the average 40 to 50 days elapsing from bud differentiation to flowering (Mauney, 1966). It is suggested, therefore, that the growth of the flowering branches in the kaolin-sprayed, and hence the less stressed plants, was extended somewhat and consequently more flowers opened. Another possible effect of the spray was a reduction in the abscission of flower squares which would have a similar effect on flower opening.

The kaolin spray significantly increased the number of flowers on July 19, but the yield harvested from these flowers was very low and apparently not affected by the kaolin spray. Evidently, the very low percent of fruit set from flowers of this date wiped out any possible differences in cotton production.

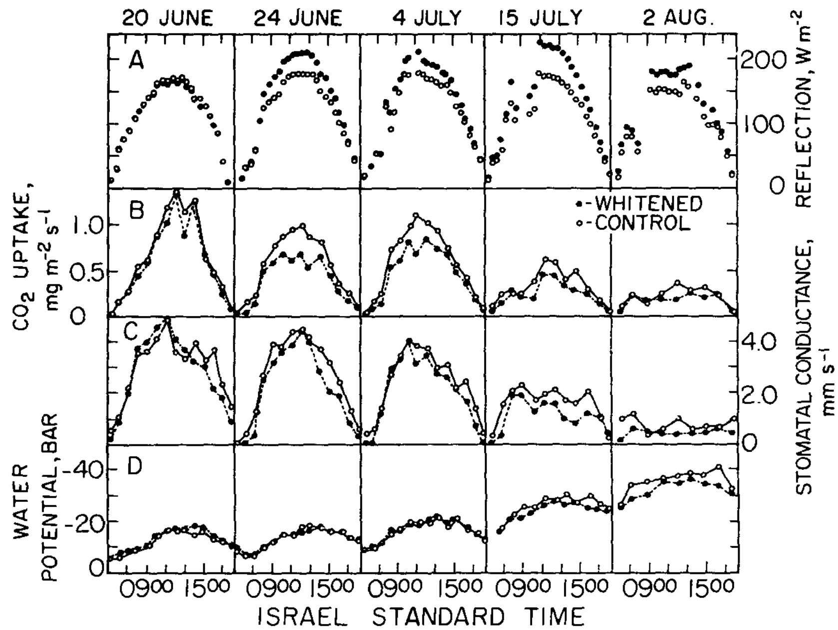

Fig. 3. Diurnal trends of canopy reflectance: (A); $^{14}CO_2$ uptake, (B); stomatal conductance, (C); leaf xylem water potential (D) of kaolin-sprayed cotton and of the unsprayed control (1976).

The different result of the treatments on total yield in the 2 years was probably caused by different row densities. The twice as high plant density in the 2nd year led to a faster drying of the soil, which brought about an earlier and steeper decrease in fruit set than in the 1st year.

Height, dry weight, and LAI of the plants were not modified significantly by the kaolin spray, (a similar effect to that found previously with sorghum; Moreshet et al., 1977). The physiological behavior of the cotton leaves was affected; both $^{14}CO_2$ uptake and stomatal conductance were reduced, the effect being stronger during the first days after the spray. The response of the stomata to our kaolin spray was different from that reported by Eveling (1969), who found that spraying stockalite clay on leaves increased the transpiration rate. Eveling refers to earlier literature which claims that dust particles wedge the stomata open. This mechanical effect on the stomates did not occur in our study where stomatal conductance was reduced. Excluding wedging, kaolin may affect the stomata in three ways: (i) The spray coating could increase the diffusive path length adding a resistance in series with the stomata; (ii) The kaolin could either fully or partially obstruct some of the stomates and increase some of the parallel resistance forming the epidermis network; (iii) the kaolin could photochemically reduce stomatal opening by attenuating the light which reaches the epidermis.

To determine which of these mechanisms was involved in reducing stomatal conductance of the kaolin-coated leaves, the relationship between solar radiation and stomatal conductance of treated and control leaves was analyzed. Since stomatal opening depends on other factors besides solar radiation, it was not possible to use the entire set of data collected in the field for this purpose. Moreshet and Falkenflug (1978), using data from this experiment, have shown that soil water potential and leaf age affected maximum stomatal conductance and the time of day at which maximum conductance occurred. These and other results (e.g. Ofir et al., 1968) indicate that solar radiation controls the stomatal opening between sunrise and the time at which maximum conductance is reached. Therefore, it can be assumed that the functional dependence between stomatal conductance and solar radiation can be determined by measurements during the opening phase of the diurnal cycle. By plotting the data for the control and treated leaves a linear relationship has been established between stomatal conductance and solar radiation (Fig. 4A).

The slopes for the kaolin-treated leaves and for the control are almost the same (4.41×10^{-6} m^3 W^{-1} s^{-1} and 4.48×10^{-6} m^3 W^{-1} s^{-1}, respectively). The intercept of the relationship in the control which was expected to be at the origin is small (+ 0.096 mm s^{-1}) and not significantly different from zero, while that of the kaolin-treated leaves was negative (− 0.324 mm s^{-1}). The statistical analysis of the regression parameters shows that the slopes are not significantly different but the difference in the intercepts is highly significant ($t = 3.82$ for df = 48).

The stomatal conductance of the untreated leaves is thus strictly proportional to the solar radiation. The kaolin spray causes a parallel downward shift of the line. This result can be explained on the assumption that the kaolin decreases a parallelly connected conductance by permanently obstructing some of the stomates.

Kaolin also reduced $^{14}CO_2$ uptake, as Fig. 3B shows. This decrease can be explained either by mechanical reduction of stomatal conductance or by attenuation of the light reaching the chloroplasts. The solar radiation correlative technique was again used to explain the mode of action of the kaolin, restricting the analysis to data collected during the opening phase of the

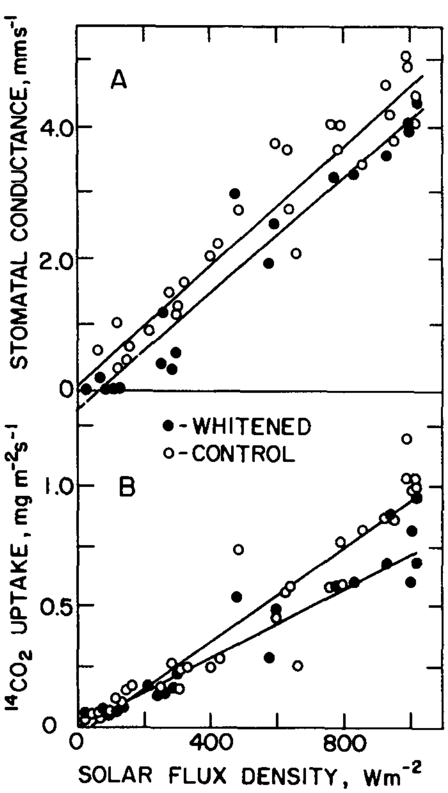

Fig. 4. Stomatal conductance (A) and $^{14}CO_2$ uptake (B) of kaolin-sprayed and unsprayed cotton leaves in relation to solar flux density during the opening phase of the stomata (1976).

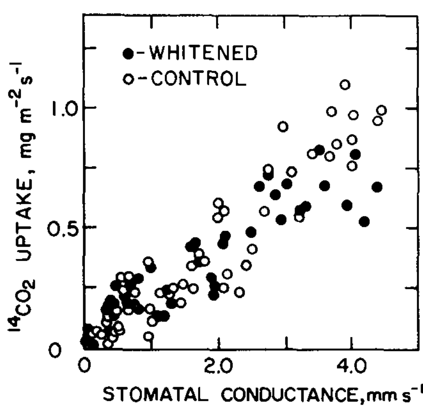

Fig. 5. The relationship between $^{14}CO_2$ uptake and stomatal conductance of kaolin-sprayed and unsprayed cotton leaves. Measured on 24 June, 15 July, and 2 Aug. 1976.

stomata to avoid possible effects of soil water potential and leaf age.

The linear regression fitted to the data plotted in Fig. 4B for the treated and control leaves have near-zero intercepts, indicating that $^{14}CO_2$ uptake is proportional to the incident radiation. This relationship agrees with field measurements by Baker and Meyer (1966). The kaolin decreases the proportionality constant. The effect is highly significant statistically and shows that the attenuation of light by the kaolin coating reduced $^{14}CO_2$ uptake. The proportionality between radiation and CO_2 uptake, and the proportional reduction of $^{14}CO_2$ uptake caused by the foliage whitening, indicate that under these field conditions the C_3 cotton leaves did not reach light saturation. However, by contrast with the effect of the whitening on the C_4 sorghum (Moreshet et al., 1977), leaf area and dry matter production were not reduced.

Table 3. $^{14}CO_2$ **concentration difference between the external atmosphere and the intercellular air space ($\Delta[CO_2]$) of dryland cotton leaves as affected by whitening with kaolin. Negba, Israel, 1976. $\Delta[CO_2] = P/C_s$, where P = $^{14}CO_2$ uptake and C_s = stomatal conductance. Values of P and C_s were taken from Fig. 4 (C_s was divided by 1.6 which is D_{H_2O}/D_{CO_2}) averaged between 0900 and 1500.**

Date	$\Delta[CO_2]$ Whitened	$\Delta[CO_2]$ Control	Relative difference
	mg m⁻¹	mg m⁻¹	%
20 June	184	203	−9.3
24 June	141	166	−15.1
4 July	181	210	−13.9
15 July	218	210	+4.5
2 Aug.	398	349	+14.2

The overall relation between CO_2 uptake and stomatal conductance, on the complete diurnal and seasonal basis is demonstrated in Fig. 5. Although it appears in Fig. 5 as if both CO_2 uptake and stomatal conductance changed in the same proportion in the two treatments due to environmental and seasonal factors, the conclusions that may be drawn from Table 3 are somewhat different. This table presents the average difference in CO_2 concentration between the external ($[CO_2]_{ex}$) and the intercellular air spaces in the leaf ($[CO_2]_{in}$), which were calculated as $([CO_2]_{ex}) - ([CO_2]_{in}) = P/C_s$. P and C_s are the $^{14}CO_2$ uptake and the stomatal conductance, respectively. The average concentration difference in the whitened leaves was larger than in the control leaves. This was presumably due to the obstruction of some of the stomates, a conclusion similar to that drawn from Fig. 4.

Assuming that stomatal conductance correlates well with transpiration, the kaolin sprays would appear to reduce transpiration more than photosynthesis. Consequently, the water status of the whitened plants should be more favorable than that of the control plants. This improvement is evidenced in Fig. 3D, which shows that the leaf xylem water potentials of kaolin-sprayed leaves showed a smaller seasonal decrease than those of the control leaves. The relative values of Table 2 emphasize the effect of whitening on the water potential.

The effect of the kaolin treatment on the water status develops after the application of the second spray and was first measured on 15 July. It is noteworthy that this date coincides with the date at which the number of flowers of the whitened plants became significantly larger than that of the control (Fig. 1). The very low rate of fruit set during that time did not allow the improved water status of the whitened plants to be reflected in the final yield in the 2nd year of the experiment.

In conclusion, the whitening of the cotton leaves by kaolin increased the yield in 1975 and increased flowers number in 1976. Leaf area and dry matter production were not affected. On the other hand, CO_2 uptake was reduced in proportion to the reduction in radiation absorption. This agrees with the finding that, under field conditions, cotton plants were not light saturated, however, leaf area and dry matter production were not affected by the reduction in radiation absorption. The reduction of the water stress observed in the whitened leaves could explain these conflicting results. The results also suggest that the improvement of the plant water status can be translated into an increase of cotton yield only if the moisture stress does not become extreme.

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