COTTON PLANT CANOPY RESPONSE TO PARTICLE FILM APPLICATION

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Abstract

Cotton (*Gossypium hirsutum,* L.) was planted in Weslaco, TX into a Raymondville clay loam soil on 8 Mar. 2000 in order to evaluate the potential use of multiple applications of a 6 % (w:v) particle film, 'Surround', to plants grown under two soil moisture regimes. Treatments were evaluated for their effect on soil and plant water status, plant canopy temperatures, and agronomic performance. 'Surround' spray applications reduced mid-day canopy temperatures typically 1.5 C and reduced leaf transpiration rates 13% compared to unsprayed plants. 'Surround'-sprayed plants had slightly improved light penetration through the canopy (P=0.13), higher canopy reflectance, and lighter leaf objective color attributes, as determined by 'L' '-a', hue angle and chroma values. Leaf chlorophyll (mg/g dw) was not affected by spraying , but leaf area (P=0.10) and plant height (P=0.07) were slightly reduced in plants given particle film applications. Raw lint yields were increased 24% when 'Surround' was applied (P=0.12). There were no differences in soil moisture between sprayed and unsprayed plants, but there was more soil moisture in the high soil moisture regime in the 25-cm depth on the second and last three of the eight measurement dates. Five inches of rainfall during the establishment of the two water regimes negated most soil moisture profile differences.

Introduction

In arid environments, about 360 units of water are normally required to produce 1 unit of cotton (Hanson, 1990). As pressure to reduce water use from non-agricultural sectors increases, exploring alternative approaches to improve cotton plant water efficiency becomes even more important. Active leaf transpiration is necessary for normal physiological plant processes and is related to yield by the relationship Yield = $k_{\text{for specific crop}}$ X Transpiration / [100 - Relative Humidity], where k = 0.089 in the case of cotton (Hanson, 1990).

One function of a light-scattering particle film is to reduce the total incident infra red radiation on a leaf surface in order to reduce the leaf heat load and thus reduce the cooling requirements required through transpiration. A particle film has the advantage over an anti-transpirant by not interfering with stomatal closure and the regulation of internal leaf temperature. A second property of this particle film is to confer pesticidal attributes against both insects and diseases (Glenn et al.,1999). In previous work (Makus, 2000), a 3% 'Surround' formulation offered leaf cooling and potential lint yield increases (P=0.14) of 22% over unsprayed plants.

The objectives of the current study were to validate the observations made in 1999 and to determine if particle film use would be more efficacious on plants grown under reduced levels of soil moisture.

Materials and Methods

On 8 Mar., 2000, seed of an experimental cotton line X2424 (Novartis, Minneapolis, MN) was planted with a cone planter into a Raymondville clay loam (Fine mixed, hyperthermic Vertic Calciustolls) soil located at the ARS facility in Weslaco, TX (Lat. 26^o 8'). Prowl (pendimethalin) was applied as a pre-emerge herbicide at 1.1 kg a.i./ha. Two irrigation regimes (main plots) and two spray treatments (sub-plots) were established. The two main plot water levels were facilitated by trickle irrigation. Supplemental water at 56 and 113 ha-mm were added to the 'low' and 'high', regimes, respectively, over the course of the growing season. Water was discontinued to the 'low' regime 70 days after planting (DAP). Sub-plot plants were sprayed ten times with 'Surround', a processed kaolin-based particle film with surfactant and adhering agents (Engelhard Corp., Iselin, NJ) at a rate of 6% product to water (w:v), from 42 to 125 DAP. 'Surround' application was renewed when approx. 25% of the plant surface was unprotected due to new growth, or after a rain. Sub-plot size was 9.1 x 2.3 m, three rows wide, on 0.76 m centers.

Soil moisture was measured eight times during the growing season by neutron probe (Troxler, Research Triange Park, NC) at depths of 25, 50, and 90 cm in access tubes located in the center of each plot in reps 2, 3, 4, 7, 8, 9 (of 10 reps, total). On five dates, 107 to 133 DAP, plot canopy temperatures were estimated around mid-day using an IR pyrometer (Omega Engineering, Stanford, CT). Continuous leaf surface canopy temperature was measured between 28 Jun and 7 Jul in the second replication by four OS36 IR thermocouples (Omega Engineering) having a 1:2 aspect ratio and centered ca. 25 cm above the middle plot row, covering ca. 0.2 m^2 of row canopy. Interior temperatures were measured continuously at 30 cm above the soil, within the plant canopy, and with in-row at soil depths of 5, 10, and 20 cm between 1 June and 15 July in replications two and four with Hobo four channel data loggers (Onset Computer Corp., Bourne, MA) located in sprayed and unsprayed sub-plots.

Porometric water measurements were taken on the fourth leaf from the apex with a LI-COR Model 1600 porometer (Lincoln, NE) between 1100 and 1330 hrs 110 and 129 DAP. At 129 DAP, the same fully expanded leaves used for porometry were excised, placed in a sealable bag and returned on ice to the lab for water potential measurements which were determined with a 'Tru-Psi' psychrometric system (Decagon Devices, Pullman, WA). Plant sap flow of a single plant from each treatment in the high soil moisture regime (in Rep 4) was measured by the heat balance method (Dynamax, Houston, TX) 198 to 200 DAP.

At 199 DAP, ten leaves (fourth leaf from the apex) in each plot were taken for leaf area determination, then frozen, lyophilized, ground through a 0.36 mm mesh sieve and stored at -20C until analyzed for chlorophyll (mg/g dw basis) and leaf nutrients N, P, K, Ca, Mg, S, Mn, Na, Fe, Al, Zn, Cu, and B. At 135 and 139 DAP, roots in the upper 0 to 30 cm soil depth from three plants per sub-plot were removed to document the extent of mycorrhizal root infection (Sylvia, 1994). At 160 DAP, plants from a 3.5 m^2 center plot area were hand harvested for raw lint yield. The experiment was analyzed as a split-plot design with ten replications, with irrigation level as main-plots, 'Surround' application as sub-plots, and when sampling occurred on two dates, dates were treated as sub-sub-plots. Soil moisture and leaf IR canopy temperatures were analyzed as repeated measures.

Results and Discussion

There were 260 mm of rainfall between 1 Mar. and 30 Jun., with no recorded precipitation in July.

Particle Film

Application of 'Surround' reduced whole plot canopy temperatures on all sampling dates, compared to the control plants (Table 1). Soil moisture to 90 cm depth was not affected. Although leaf water potentials were not significantly different between leaves of sprayed and control plants (data not shown), leaf temperatures, stomatal conductance, and transpiration rates were lower in sprayed leaves at the time of sampling, suggesting that these leaves were less stressed (Table 2). At the time of sampling, light intensity, which can regulate stomatal aperture, was similar for all treatments.

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'Surround' applications reduced average exterior canopy temperature 1.4 to 1.6 °C (between 1100 to 1700 hrs) during the 180 to 189 DAP measurement period, compared to unsprayed plants (data not shown). Season interior plant canopy temperatures at 30 cm and soil temperatures at 5, 10, and 20 cm were generally reduced by 'Surround' application (Figure 1).

Sprayed-plants had slightly improved light penetration through the canopy (P=0.13), improved canopy reflectance, and lighter leaf objective color attributes, as determined by 'L' '-a', hue angle and chroma values (Table 3). There were no differences in leaf chlorophyll content between treatments. In preliminary greenhouse experiments, plants receiving sequentially higher particle film rates had increasingly higher SPAD (greenness) readings. However, the data from Table 3 would suggest that SPAD readings are over-estimating leaf greenness. SPAD measurements are based upon the transmittance of two known wavelengths through the leaf, and these may be scattered by the 'Surround', thus reducing the signature signal to the instrument. The estimated PAR reduction from a simulated spraying of 6% 'Surround' on to clear glass plates was approx. 34%. Only when a 63% light reduction occurred for eight day periods, particularly during boll development, was assimilate supply decreased (Zhao and Oosterhuis, 1998).

Leaf blade N, Ca, S, Mg, Fe, and Mn, as well as total cation concentrations, were greater in control compared to 'Surround'-sprayed leaves (Table 4). Sap flow measured 198 to 200 DAP was greater for an unsprayed vs 'Surround'-sprayed plant (Figure 2), supporting the hypothesis that control leaves may have accumulated higher nutrients because of the greater volume of transpirational water needed for leaf cooling.

Near the end of the growing season plant height and leaf area were nominally reduced by 'Surround' applications (Table 5). Raw lint yields were significantly higher for 'Surround'-sprayed plants compared to control plants (P=0.14). Use of a 3 % 'Surround' formulation in 1999 resulted in a similar quantitative yield response (Makus, 2000). Insecticides were avoided until late in the season, when it became apparent that 'Surround', as a pest deterrent, was not effective in weevil control in this experiment. From 196 to 209 DAP, daily weevil trap counts averaged 31, with counts as high as 160 (T. Sappington, ARS, Weslaco), which suggested that weevils were a major factor in reducing yield in both treatments..

Soil Moisture Regime

Mean soil moisture at the 25 cm soil depth, summed over the growing season, was 444 and 479 kg/m^3 for 'low' and 'high' soil moisture regime plants, respectively (Table 1). The inability to measure other residual soil moisture differences between treatments and moisture regimes may have been due to the large recharge in May from rainfall (123 mm) and/or from plant roots reaching a relatively high water table. Leaf chlorophyll, N, S, and P were higher in plants grown under 'high' soil moisture (Tables 3, 4). 'Surround' applied to plants grown under high soil moisture reduced leaf Na levels, compared to other treatment / soil moisture combinations. Leaf Fe levels were lowest in 'Surround'-sprayed plants grown in 'low' soil moisture.

There was a greater mycorrhizal association in cotton roots grown with less water at the 25 cm depth (Table 5). This association is a logical one since mycorrhizae can reduce water stress when plants are subjected to drought stress (Augé, et al. 1986). Mycorrhyzae can also improve P uptake when P soil levels are low, however, in this experiment leaf P levels were higher in the 'high' soil regime, suggesting again the probable role of greater nutrient transport associated with the higher soil moisture regime.

Summary

The particle film, 'Surround', appears to be a potential tool for reducing solar- induced canopy heating and subsequently improving cotton yields. This is the second year we have seen nominal yield increases with 'Surround' applied to irrigated cotton. Application to dryland cotton may prove even more beneficial and should be explored.

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Table 1. Season soil moisture and leaf canopy temperatures of plants grown under two soil moisture regimes and with or without 'Surround' applications.

	Soil moisture depth (cm) kg · m^3			Leaf temp.
	25	50	90	C
Day:	**[Z]	**	**	**
Irrigation level (I):				
Low	444	494	396	36.8
High	479	496	404	36.6
	**	NS	NS	NS
Treatment (T):				
Control	464	490	385	37.5
'Surround'	460	500	415	35.9
	NS	NS	NS	**
Interactions:				
I x T	NS	NS	NS	NS
Day x I	**	NS	NS	NS
Day x T	NS	NS	*	NS
Day x I x T	NS	NS	NS	NS

[Z]NS, *, ** = Not significant and significant at P=0.05, P=0.01, respectively.

Table 2. Porometric response of leaves from 'Surround'-sprayed and unsprayed plants grown under two water regimes.

	Stomatal Conductance cm · s^{-1}	Transpiration µg · cm^{-2} · s^{-1}	Temp. C	PAR[Z] µMol · m^{-2} · s^{-1}
Day:				
June 24	1.23	14.6	31.8	1858
July 14	0.99	18.5	34.8	2028
	**[Y]	**	**	**
Irrigation level (I):				
Low	1.10	17.0	33.3	1965
High	1.11	17.0	33.3	1962
	NS	NS	NS	NS
Treatments (T):				
Control	1.19	18.2	33.5	1966
'Surround'	1.03	15.8	33.1	1960
	**	**	**	NS
Interactions:				
I x T	NS	NS	NS	NS
Day x I	NS	NS	NS	NS
Day x T	*	NS	*	NS
Day x I x T	NS	NS	NS	NS

[Z]Photosynthetically active radiation between 400 and 700 nm.
[Y]NS, *, ** = not significant and significant at P=0.05, P=0.01, respectively.

Table 3. Canopy light, infiltration, reflectance, and objective leaf color attributes of 'Surround'-sprayed and unsprayed plants grown under two soil moisture regimes.[Z]

	Canopy light			Leaf
	Below[w]	Top:bottom ratio	Reflected[w]	Chloro (mg/g dw)
Day:	**[Y]	**	-	-
Irrigation level (I):				
Low	9.8	368 b	133 a	4.4
High	9.7	513 a	123 b	5.0
	NS	0.13[X]	*	*
Treatment (T):				
Control	8.3 b	481 a	79 b	4.9
'Surround'	11.2 a	400 b	177 a	4.6
	0.18	0.19	**	NS
Interactions:				
I x T	NS	NS	NS	NS
Day x I	NS	NS	-	-
Day x T	*	NS	-	-
Day x I x T	0.06	NS	-	-

	Leaf color attributes				
	L (lightness)	-a (greenness)	Hue angle (arctan a/b)	Chroma $(a^2 + b^2)^{1/2}$	SPAD
Day:	-	-	-	-	-
Irrigation level (I):					
Low	52.3	8.2	-29.1	12.8 b	45.2
High	51.7	8.5	-30.7	13.4 a	44.3
	NS	NS	NS	0.14[X]	NS
Treatment (T):					
Control	38.8 b	13.0 a	-53.9 b	22.1 a	41.6 b
'Surround'	65.1 a	3.8 b	-6.0 a	4.1 b	47.9 a
	**	**	**	**	**
Interactions:					
I x T	NS	NS	NS	NS	NS
Day x I	-	-	-	-	-
Day x T	-	-	-	-	-
Day x I x T	-	-	-	-	-

[Z]Light penetration measurements made 101 and 122 DAP with a LI-191SA Line Quantum Sensor; objective leaf color 123 DAP with a Minolta CR-200 Chroma Meter; canopy reflectance (with an inverted LI-191SA) and leaf chlorophyll 134 DAP.
[Y]NS, *, ** = Not significant and significant at P=0.05, P=0.01, levels respectively.
[X]Prob. > 'F' value.
[W]Units: m Mol. PAR / s/ m^2

Table 4. Mean nutrient concentrations (dry wt. basis) found in the fourth fully expanded cotton leaf 132 DAP from plants grown under two water regimes, with and without 'Surround' applications.[Z]

	%				
	N	Ca	S	Mg	P
Irrigation level (I):					
Low	2.71 b	3.59	1.12	0.881	0.127
High	2.90 a	3.64	1.21	0.860	0.142
	0.07[Y]	NS[X]	*	NS	*
Treatment (T):					
Control	2.91	3.82	1.22	0.925	0.136
'Surround'	2.70	3.41	1.11	0.816	0.134
	**	**	0.06	**	NS
Interaction:					
I x T	0.07	NS	NS	NS	NS

	µg · g^{-1}				%
	Na	Al	Fe	Mn	Total Cations
Irrigation level (I):					
Low	2836	411	207	85.6	6.36
High	2395	422	240	89.5	6.52
	0	NS	NS	NS	NS
Treatment (T):					
Control	2679	359	240	93.	6.74
'Surround'	2552	474	208	81.6	6.13
	NS	**	*	**	**
Interaction:					
I x T	*	NS	*	NS	NS

[Z]No significant main effect or interaction was found for K (1.60%) or NO_3 (508), B (121), Zn (13.5), and Cu (9.0) µg · g^{-1}, respectively.
[Y]Probability of a greater 'F' value.
[X]NS, *, ** = Not significant and significant at P = 0.05, P = 0.01, respectively.

Table 5. Agronomic response of 'X2424' cotton to two irrigation regimes and 'Surround' applications.

	Yield kg · ha^{-1}	Stand ha (x 10^3)	Plant height cm	Leaf area cm^2	Myco. root rating[Z]
Irrigation level (I):					
Low	185	88	143	110	2.2 a
High	219	103	148	105	1.5 b
	NS[Y]	NS	NS	NS	**
Treatment (T):					
Control	181 b	99	148 a	110 a	2.0
'Surround'	224 a	90	143 b	104 b	1.6
		0.12[X]	NS	0.07	0.10 NS
Interactions:					
I x T	NS	NS	NS	NS	NS

[Z]Mycorrhizal root rating: 1 (least) to 5 (most abundant).
[Y]NS, ** = Not significant and significant at P=0.01, respectively.
[X]Probability of a greater 'F' value.

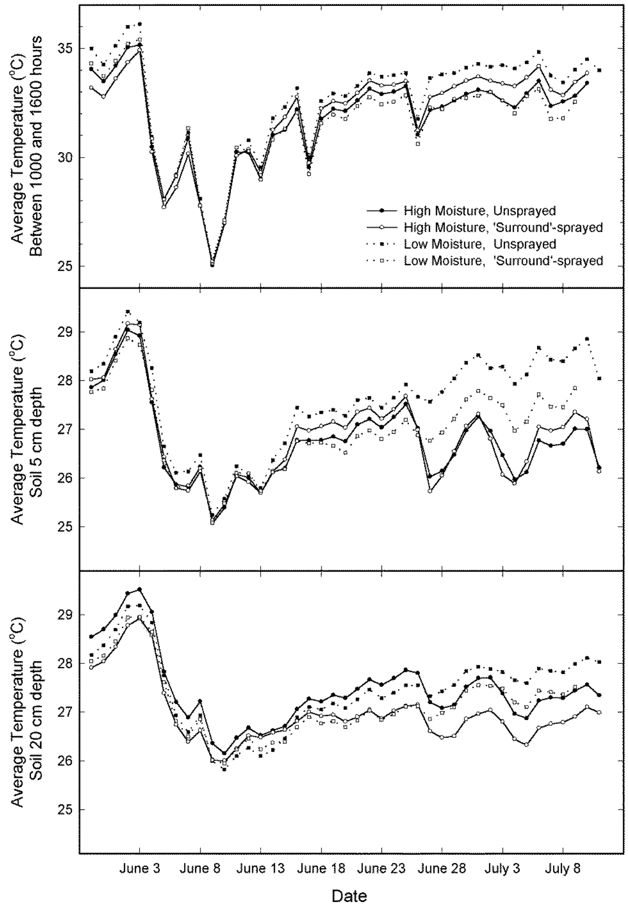

Figure 1. Season with-in canopy air temperatures at 30 cm and mean daily soil temperatures at 5 and 20 cm depth, between 1000 and 1600 hrs, from 83 to 125 DAP.

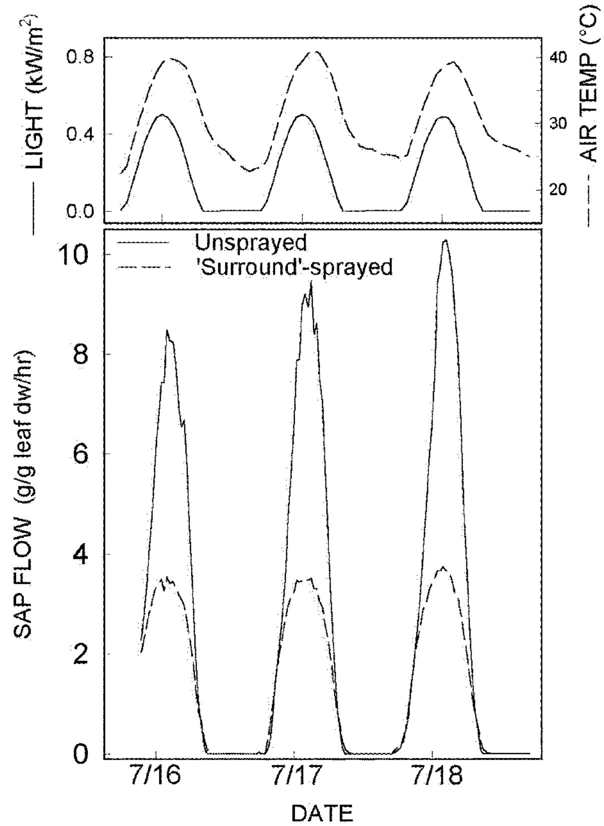

Figure 2. Sap flow of an unsprayed and 'Surround'-sprayed plant 198 to 200 DAP. Light measurements were PAR between 400 - 700 nm.