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Misting External Shade Cloths Part I: Relief from the Heat?

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No one has to tell North Carolina greenhouse growers about hot weather. Delayed flowering and reduced crop quality are some of the more obvious problems it causes. Reduced growth is less obvious, but since it can be combined with reduced quality it need not be considered separately.

Heat effects are most pronounced at the exhaust ends of greenhouses given that temperature rises significantly from one end of a house to the other. In a well designed evaporative pad cooled greenhouse containing a substantial amount of mature plant material, air temperatures at the inside face of the pads can range from 76 to 82 °F on a typical summer day in North Carolina, while air temperatures at the exhaust end can be within a few degrees of outside air temperature; sometimes in excess of 95 °F. In greenhouses with under-designed cooling systems, or in houses with insufficient or immature plant material, exhaust temperatures can exceed outside temperatures by 10 °F or more.

As if this weren't bad enough, the addition of pest exclusion screening to greenhouses will make the problem even worse. Considering the example recently presented by Baker et al. (1993), selecting screening to increase the pressure drop across the exhaust fans to 0.15" of water can be expected to increase exhaust temperatures by as much as 2 °F. As dirt builds up on the screening material, air flow will decrease, thereby increasing exhaust temperatures even more.

Until now, cooling remedies have been few. Heat tolerant cultivars and under-the-cloth venting (for short day plants) can be used to minimize some effects. Internal or external shade cloths have been used to reduce incoming solar insolation; however, traditional (black and green) shade cloths reduce greenhouse energy gains and internal temperatures by less than 50% of their shade ratings (due to energy trapped by the cloths which is then transferred into the greenhouse). White shade cloths do somewhat better, but the shade ratings available are limited to about 30%, which restricts the amount of cooling they can provide.

Shade cloths might be an effective means of lowering greenhouse temperatures if the energy trapped in the material could be dissipated in some way. One possibility would be to increase the air flow over the material, but the only practical means of doing this is wind, which is not very dependable. It could be accomplished by varying the radiation characteristics of the material; but this is more complicated than one might expect, and it is generally limited in effectiveness anyway.

One attractive alternative is to evaporate water from the surface of the shade cloth. As long as the shade cloth is external to the greenhouse, transfer of the resultant water vapor to the atmosphere should not increase the relative humidity or the heat load inside the greenhouse. Since water evaporation is an extremely efficient means of transferring heat, and since water availability is not generally a limitation for most North Carolina growers, we decided to examine the feasibility of this approach for improving the efficiency of external shade cloths.

To-date, we have conducted two experiments on shade cloth misting; one in the summer of 1992 and one in the summer of 1993. The first was designed to evaluate the potential of shade cloth misting for improving cooling while the second was designed to evaluate differences in the performance of shade cloths of various shade ratings and colors. This article (Part I of the series) will attempt to summarize the results of the 1992 tests relating to the potential of the approach while the second article of the series will summarize the results of the 1993 tests and will touch on the performance of misted and un-misted black vs. white cloths as well as misted and un-misted white vs. no shade.

Materials and Methods

Both experiments were conducted in two, 22' × 40', double-poly covered Quonset greenhouses located at the Horticultural Field Laboratory on Beryl Road in Raleigh, N.C. In the 1992 experiment, a black polyethylene 55% shade cloth (flat weave) was applied alternately to each greenhouse on a weekly schedule. The shaded house was considered to be the test house and the unshaded house the control. The shade cloth was alternated between the houses to allow the statistical removal of house differences.

To minimize the confounding of weather differences with the performance data, the black shade cloth was misted every other day. Water was applied using 3 commonly available, flat-profile sprinkler irrigation hoses mounted at the top of the test greenhouse. The feed pressure was regulated to 12 psi to limit the amount of water applied and to minimize rupture problems experienced when the hoses were operated at higher pressures. Misting was accomplished 30 seconds out of every 3 minutes whenever solar radiation was greater than 400 W/m^2 (the level of a mostly-cloudy summer day at noon or of a bright sunny day at 9 am).

The houses were planted with tomatoes on 19 June 1992 to provide adequate plant material for transpiration. One hundred and forty-four plants were transplanted into 5 gal bags containing ProMix BX supplemented with 50% by-volume aged pine bark. Water was supplied via drip irrigation at the rate of 2 to 3 quarts per day per plant.

Inside temperatures were measured using thermocouples. Ground temperatures were measured at three locations, and leaf temperatures were measured on six plants (two leaves each) per house. Inside humidity conditions were monitored with dry and wet bulb temperatures measured in aspirated boxes at four locations: two at the air inlet, one at the center of the house and one at the exhaust fan inlet.

Dry bulb temperatures above and within the canopy were measured with thermocouples mounted in 2" PVC pipe elbows with small axial bladed fans mounted in one end.

Treatments were initiated on 10 July 1992 and continued for 9 weeks. At the end of the experiment, both houses were left unshaded (and un-misted) for 10 days to provide a base line for comparison. The water flow rates to the sprinkler hoses were estimated by placing the individual hoses into containers, positioned at the same elevation as the hose inlets, and measuring the water collected during three 1-minute periods. Knowing this, and the total misting time recorded by the computer, water consumption due to misting was estimated.

Data Analysis

The overall effect of shading and misting was twofold: ❶ a reduction in the air temperature rise and total energy gain in the shaded house compared to the control house; and ❷ a reduction in the amount of time the evaporative pad ran in the shaded house (same basis). The effect on total energy gain was examined by considering the percentage reduction in total energy gain from inlet to exhaust end of the shaded house compared to the unshaded control. The effect on sensible energy gain (that energy related to a rise in temperature) was examined by considering the percentage reduction in air temperature rise on the same basis. Since both effectively represent energy gains, if the shade cloth were 100% efficient they should both be equal to the shade rating of the cloth (in this case, about 55%). Anything less than the shade cloth rating suggests a shade cloth efficiency less than 100%.

Leaf temperature rise is not directly related to energy gain because the plants exert some control over the temperature of their leaves by controlling stomatal openings. Leaf temperature rise in a greenhouse is generally nonlinear from one end of the house to the other, and it is not closely related to shade cloth rating. A better measure of plant response (and the one chosen for this study) is maximum leaf temperature found in the greenhouse, usually found on plants at the exhaust end of the greenhouse.

Variation in ground temperature from end-to-end was also nonlinear, but not for the same reasons as leaf temperatures. Alternating sunlight and shade exposure of the three measurement locations in each house (air inlet, middle of the house, and exhaust fan outlet) throughout the day caused locations near the air inlet end of the houses to be occasionally higher than those nearer the exhaust fan outlet end. Percentage reduction in <u>average</u> ground temperature was chosen as the best alternative.

Results and Discussion

Evaporative pad run times in the test house were significantly reduced by misting (data not shown). On average, when only a shade cloth was used the pad ran 72% of the time that it did in the control house. On the other hand, when the shade cloth was misted the pad ran only 40% of the time it did in the control house. This represents a 45% reduction in evaporative-pad run times. The run times for the other two cooling modes on the 3-stage cooling system (low-speed exhaust fan and high-speed exhaust fan only) were not significantly affected by shade cloth misting.

Water consumption varied with the weather, as might be expected, but typically shade cloth misting was estimated to consume about 200 to 300 gal/day, or about 1/2 that estimated to have been used by the evaporative pad system in the control house. Considering the reduced running time of the evaporative pads in the shaded house, it is possible that very little additional water was actually used by the shaded house during misting. More careful testing will be required to answer the question of water use definitively.

When the evaporative pads in both houses were running, the shaded house experienced reduced energy and temperature levels both with and without misting (Table 1). The dry shade cloth reduced total energy gain by 24.0%, compared to the unshaded control, which is about 44% of the shade rating (it was a 55% shade cloth) of the cloth. This means that a dry black shade cloth can be expected to perform at an efficiency of only 44%. Likewise, the dry shade cloth reduced air temperature rise by only 18.5% over the control, which is about 34% of the shade rating. Maximum leaf temperatures and average ground temperatures were reduced by only 5.4% and 13.9%, respectively. These data illustrate the inefficiency of traditional shade cloths in very a striking way.

Table 1. Reductions in energy gain, air temperature rise, maximum leaf temperature and average ground temperature in the test house (compared to no shade) for both shade and shade plus misting.

Parameter	Mean reduction (%) Shade only	Mean reduction (%) Shade + mist	LSD* (%)
energy gain	24.0	39.4	1.5
air temperature rise	18.5	39.4	2.2
maximum leaf temp.	5.4	8.3	0.7
average ground temp.	13.9	17.6	1.4

*Least significant difference at $\alpha = 0.01$.

When misting was employed, total energy gain and air temperature rise were both reduced by 39.4%, compared to the unshaded control house. This corresponds to a shade cloth efficiency of 72% and represents a more than doubling of efficiency with respect to air temperature rise and a 64% improvement with respect to total energy gain (as compared to the unshaded control house). Maximum leaf temperatures were reduced by 8.3% over the control (a 54% improvement) while average ground temperatures were reduced by 17.6% over the control (a 27% improvement).

At first glance, the effect of misting on leaf and ground temperatures appears to be much less than on total energy gain and air temperature rise. This is illusory in that the data for leaf temperature and ground temperature are percentages of maximum and average temperatures, respectively, while the data for energy gain and air temperature rise are percentages of absolute differences between one end of the house and the other. The latter are generally smaller numbers and thus produce higher percentages. For example, energy gain in the control house ranged from 2.2 to 6.2 BTU/lb_{air}, with a mean of 4.34 BTU/lb_{air} whereas the mean leaf temperature at the exhaust end of the house ranged from 83.1 to 94.3 °F, with a mean of 88.3 °F. The mean rise in air temperature in the control house ranged from 4 to 15.4 °F, with a mean of 10.4 °F, and the average ground temperature ranged from 85.1 to 120.6 °F, with a mean of 104.9 °F.

Wind speed was found to increase the efficiency of the dry shade cloth to a greater extent than that of the misted shade cloth. This is probably because increased air movement over the cloth improved the rate of heat removal significantly when the cloth was dry but when it was wet the evaporating moisture had probably already removed most of the heat so that increased wind speed provided very little advantage. In no case did increased wind speed do as much for efficiency as misting.

The ability of misting to improve shade cloth performance was also found to improve with increasing outside temperature and with decreasing outside relative humidity. Since the highest temperatures generally always accompany the lowest relative humidities, this simply means that the hotter the day, the more effective the misting.

Translating the percentages listed in Table 1 to absolute numbers can be helpful. Table 2 presents air, leaf and ground temperatures calculated from the performance data, assuming maximum observed values in the control house. Absolute energy levels are not presented (they are not particularly useful anyway) and air temperature rise has been converted to the air temperature at the exhaust end of the house, assuming an inlet temperature of 80 °F leaving the evaporative pad (typical when outside summertime conditions are 95 °F and 55% relative humidity). The numbers presented in Table 2 have not been adjusted for the higher than average efficiency misting provides on hotter days (see above).

The 39.4% reduction in air temperature rise provided by the misted 55% shade cloth would produce an air temperature at the exhaust end of the house about 6.1 °F cooler than in an unshaded house and 3.2 °F cooler than in a house using shade only. Note that the reduced temperature would more than compensate for the 2 °F increase caused by the addition of insect screening

Table 2. Absolute values of air, leaf and ground temperatures calculated using the performance data from Table 1 and the maximum observed values of each parameter.

House	Air temp at exhaust end (°F)	Leaf temp at exhaust end (°F)	Average ground temp (°F)
Unshaded	95.4	94.3	120.6
55% shade cloth only	92.6	89.2	103.8
55% shade + misting	89.4	86.4	99.4

mentioned earlier in this article. Considering leaf temperature, shade alone would reduce leaf temperatures at the exhaust end from 94.3 °F to 89.2 °F, while misting would be expected to provide an additional 3.1 °F reduction to 86.4 °F.

Shade alone was more effective in reducing ground temperatures than any other parameter; furthermore, it was proportionally more effective than shade plus misting (the reasons for this are unknown). Shading with a 55% cloth by itself should reduce ground temperatures from 120.6 °F to 103.8 °F (a reduction of 16.8 °F) while adding misting would probably reduce them only an additional 5.4 °F (significant, but proportionally not as big of a decrease as for air or leaf temperature).

Caveats

Although shade cloth misting performed very well in this study it will not be applicable to all situations and all areas. It may not be suitable, for example, in areas where the water contains enough minerals (iron for example) to cloud or discolor the shade cloth and/or greenhouse cover. The water used in this study was relatively hard but the iron content was low. Furthermore, sufficient excess water was applied (although not a great deal) and rainfall was frequent enough such that no deposits were observed on either the shade cloth or cover surfaces at the end of the study.

Misting is obviously not suitable for internally mounted shade cloths, since the higher humidities in the greenhouse and the removal of water vapor from the area of the shade cloth are likely to prove to be insurmountable problems; however, external retractable shade cloths can certainly be designed if the benefits of misting prove to be as great as indicated by this study.

Conclusions

Shade cloth misting looks like it will provide positive and substantial benefits, subject to the caveats outlined above. We have not developed or tested alternative methods for applying the mist (sprinkler irrigation hoses have some drawbacks) but that is unlikely to present major problems, provided we can get the necessary funding to do the testing. Some optimization of water usage can probably be accomplished also; but that, too, will require additional study.

The results from the 1993 study have now been analyzed and will be presented in the second article of this series to be published in a future edition of the NCCFGA Bulletin. These results are very interesting relative to the comparison between black and white cloths of the same weave and should go a long way toward helping us understand the benefits and limitations of misting and shading in general.

References

Baker, J.R., M.B. Crouse and E.A. Shearin. 1993. Screening as part of insect and disease management in the greenhouse. North Carolina Commercial Flower Growers' Bulletin 38(4): 12–17.