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Misting External Shade Cloths Part II: Does It Matter What Kind of Cloth?

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Part I of this series addressed the basic limitations of shade cloths for cooling greenhouses and suggested misting as a means of overcoming those limitations. This article (Part II) will extend the results presented earlier by considering shade percentage, type of weave and color, and how shade cloth misting is affected by those factors.

Early on, we assumed that color would play a major role in shade cloth performance, and some of our laboratory tests seemed to confirm that assumption. Unfortunately, we were unable to model the effects of color (which is just another way of saying that we didn't understand it). We had a better feel for shade percentage, but almost no feel for what to expect from type of weave. To investigate these parameters further, we initiated a study in the summer of 1993 in which we added the three factors mentioned above (shade percentage, cloth color and type of weave) to a study similar to that reported on in Part I (*in the April, 1994 NCFG Bulletin*). What we found in this second study was as surprising as it was interesting.

Materials and Methods

As in the previous year, the 1993 experiments were conducted in two, 22' × 40', double-poly covered Quonset greenhouses located at the Horticulture Field Laboratory in Raleigh. 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.

Differences in 1993 included the introduction of a 60% knitted black cloth, a white cloth of the same weave and thread count as the 60% black cloth, and a 30%, flat-weave, black cloth, in addition to the original 55% black cloth used in the 1992 study. Table 1 shows the cloths used, the shade ratings listed by the manufacturer, and the shade ratings we measured using both a black-and-white pyranometer (for total solar radiation) and a Li-Cor PAR (photosynthetically-active radiation) sensor. Note that even though the black and white knitted cloths had the same thread count, they did not have the same measured shade ratings. All shade ratings were obtained with the cloths oriented perpendicular to the radiation of the sun.

The PAR values (Table 1) represent the blockage of only that part of the solar spectrum used by plants and would be expected to correspond closely to the published shade ratings (which are generally based upon visible light). These values tell us how the cloths will perform with regard to the reduction of "light," but they do not tell us much about how performance with respect to cooling. The solar radiation values represent the blockage of a larger portion of the spectrum including some, but not all, of the infrared energy, but still do not give us much insight as to how well the cloths will cool a greenhouse. Only actual testing can provide that information.

The shade cloths listed in Table 1 were applied to the greenhouses in the combinations outlined in Table 2, each cloth being applied to the appropriate house during the first week of a two-week period, after which time the cloths were switched to the opposite house for the second week of the period. As before, switching was done to facilitate statistical separation of house differences from shade cloth differences. A one week period where no shade was applied to either house was included to facilitate statistical separation as well.

As in 1992, the shade cloth on the "test" house was misted every other day for the entire period (Table 2). Usually, the misted shade cloth was the black cloth; however, when the white cloth was compared to "no cloth," the white cloth was misted. The "control" house was always dry. Also as in 1992, misting was accomplished using three commonly available, flat-profile sprinkler irrigation hoses mounted at the top of the "test" greenhouse. The feed pressure was regulated to 12 psi. Misting was intermittent, 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 29 June 1993 to provide plant material for transpiration. One hundred and forty-four plants were transplanted into 5 gallon bags containing Pro-Mix 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. Liquid fertilizer (20-20-20) was supplied every two weeks using a hozon applicator.

Temperatures inside the greenhouse were measured using thermocouples. Leaf temperatures were measured on six plants (two leaves each) per house. Indoor air temperature and relative humidity conditions were monitored with dry and wet bulb temperatures that were

Table 1. Manufacturers' and measured shade ratings of the cloths used in this study.

Cloth	Mfrs' shade rating (%)	Measured shade rating (solar rad.) (%)	Measured shade rating (PAR) (%)
40% white*	40	33	39
30% black**	30	27	31
55% black**	55	54	53
60% black***	60	53	55

*This is a knitted weave with the same thread count per inch as the 60% black cloth.
**These cloths are flat weave materials.
***Knitted weave cloth.

Table 2. Shade cloth combinations presented in the order of testing.

"Test" (mist)	"Control" (dry)	Duration (weeks)
55% black	40% white	2
40% white	none	2
none	none	1
30% black	40% white	2
60% black	40% white	2

taken in aspirated boxes at four locations: two at the 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 19 July 1993 and continued for 9 weeks, including a week with no shade cloth on either house. At the end of the experiment, both houses were left unshaded (and unmisted) for an additional week. The unshaded periods were then used to adjust for house differences. After the study was completed, water flow rates were measured using a flow meter inserted into the line ahead of the pressure regulator. The average flow rate was determined to be about 9 gpm. Knowing this, and the total misting time recorded by the computer, water consumption was estimated.

Results and Discussion

The shade treatment effects were analyzed by comparing differences in: ❶ overall energy gain; ❷ air temperature rise; ❸ leaf temperatures at the exhaust end of the house; and ❹ electrical energy consumption. For all but leaf temperature in the "white cloth vs. none" case, misting improved performance (Table 3). For the "30% black vs. white" case, the dry white cloth outperformed the misted 30% black cloth; however, the other black cloths outperformed the dry white cloth when they were misted (Table 3).

Water consumption was higher than expected. The estimate of 200 to 300 gallons per day determined in the 1992 study was found to be low by a factor of about 3 (daily usage was about 600 to 900 gallons per day). The discrepancy between years was attributed to errors in the 1992 measurements and the higher flow is thought to be a more realistic estimate of the usage in both years. It should be noted that no optimization of flow was attempted in either year; however, studies conducted in 1994 show that daily flows can easily be curtailed to about 170 gallons per day, less than that used by the evaporative pads, without affecting performance.

Differences in overall energy gain, air temperature rise and leaf temperature were evaluated only during times when identical equipment was running in both houses. Electrical energy consumption differences were determined on an overall basis. Percentage reductions of these factors were calculated using the "control" condition as a base.

The results for the various test combinations are tabulated in Table 3. Considering the "white cloth vs. none" case first, the dry white cloth reduced energy gain and air temperature rise by 30% and 27%, respectively. Misting improved those reductions to 40% and 42%, about the same reduction observed for the misted 55% black cloth in 1992. Leaf temperatures at the exhaust end of the house were reduced by 6% when the cloth was dry and that value did not significantly change when the cloth was misted. Reduction in energy consumption was affected by misting, with a 25% reduction in energy consumption observed when the cloth was dry and a 33% reduction when it was misted, both compared to no shade at all.

Note that the misted reductions in energy gain and air temperature rise were equal to or greater than the PAR shade rating for the white cloth (38%). Defining a cooling performance factor as the amount of energy or temperature reduction divided by the shade rating, we see that when misted the white cloth would be expected

Table 3. Mean percentage reductions in energy gain, air temperature rise, maximum leaf temperature, and electrical energy consumption. Comparisons of each material when dry and wet were made with respect to the "control" condition listed; controls were always dry.

Cloth combinations	% reduction in energy gain		% reduction in air rise		% reduction in leaf temperature		% reduction in energy consumption	
(test vs. control)	dry	wet	dry	wet	dry	wet	dry	wet
white vs. none	30	40	27	42	6	7*	25	33
30% black vs. white	-23	-8	-24	6	-2	0	-21	-8
55% black vs. white	-19	14	-20	20	0	3	-2	13
60% black vs. white	-4	22	-17	31	0	4	-7	14

*Not significantly different fromt the dry case ($\alpha = 0.05$).

to reduce energy and temperature gains by as much as 1.0 to 1.05 times the shade rating.

Black vs. White. The remaining data in Table 3 show the performance of the black cloths compared to the white cloth. In all cases, the black cloth was the one that was misted. Note that when the 30% black cloth was dry, the white cloth outperformed it in all respects. This agrees with some of our earlier laboratory and field tests, and to some degree, with intuition. When misted, however, the 30% black cloth performed nearly as well as the dry white cloth. Considering the higher cost of the white cloth (generally 2 to 3 times that of an equivalent weave black cloth) and the higher PAR blockage by the white cloth (38% vs. 30%), misting a 30% black cloth might make more sense than using an unmisted 40% white cloth. On the other hand, if misting cannot be used, say in a situation where the shade cloth is mounted inside the greenhouse, a 40% white cloth should perform significantly better than a 30% black cloth.

Comparing the two heavier black cloths to the white, note that the white cloth generally outperformed the black when dry (except for leaf temperature), but when either black cloth was misted it outperformed the white by a substantial margin. Note also that the dry 55% black cloth performed only marginally better than the dry 30% black cloth (both were of the same material and weave). When dry, energy gains were 19% and 20% greater, respectively; and air temperature rises were 20% and 24% larger, respectively, than under the dry white cloth. When misted, however, the performance of the 55% black cloth jumped dramatically. This is undoubtedly due to the fact that the "dry" performance was inhibited by the greater amount of energy "trapped" in the heavier cloth. When misted, however, that energy was removed by the evaporating water yielding the advantage to the heavier cloth.

Knitted vs. flat weave. One interesting feature of the data in Table 3 is the apparent increased performance of the 60% knitted black cloth compared to the 55% flat weave black cloth. When dry, the 60% black cloth produced greater reductions in all categories except electrical energy consumption. If the performance of the misted 60% black cloth is adjusted for the expected performance of a "misted" 40% white cloth (derived from the comparison of "white vs. none" above), the misted black cloth reduced energy, air temperature, leaf temperature and electrical energy consumption by 9%, 3% and 4%, compared to that of the misted 40% white cloth. Making the same adjustment for the misted 55%

black cloth shows that it performed about the same as the misted 40% white cloth, which agrees with the results of the 1992 study where the same 55% black cloth (when misted) reduced energy gains and air temperature rises by about 40% (compared to no shade).

There are several possible reasons for the difference in performance between the two black cloths. One possibility is the knitted cloths were identical in size, covering the entire greenhouse with a few inches to spare, whereas the flat-weave cloth was slightly smaller, leaving a space uncovered at the base of the greenhouse when it was in position. Another possible reason is that the knitted cloths were considerably thicker that the flat weave cloths. Preliminary measurements suggest that this produces a higher shade rating when the sun strikes the cloth at an angle. Rather than speculate at this point, however, I would prefer to wait for the analysis of the 1994 study, in which one of the objectives was a direct comparison between the 60% black knitted and the 55% black flat-weave.

Conclusions

The results of this study, along with those of previous years, have finally provided some insight into shade cloth behavior we feel support some general comments: ❶ It is apparent that shade cloths used for cooling do not perform as well as their shade ratings suggest, regardless of color; ❷ White cloths do out-cool black cloths when both are dry; ❸ However, when two cloths of identical thread count and weave are misted (black vs. white), the black will reduce temperatures about 13% more than the white cloth; ❹ On the other hand, black shade cloth appears to allow less light (PAR) into the greenhouse (about 25% less) than white cloth.

Water usage for the 1992 and 1993 studies was higher than expected, but the method of water application in those two years was designed for simplicity of implementation, not water conservation. Although the sprinkler hoses functioned reasonably well (after pressures were reduced to eliminate blowouts), they suffered from several limitations and will probably be applicable only for small greenhouses or situations where the cost of water is not a factor. Where they are found to be applicable, almost certainly some type of water reclamation will need to be employed (none was used in either the 1992 or 1993 studies), as nearly 80% of the water applied was wasted. Preliminary results from the 1994 study using inexpensive sprinkler heads mounted in a PVC header suggest that water usage can be reduced to an inconsequential amount, even without water reclamation.

The feasibility of shade cloth misting does not appear to be in question in those situations for which it is suited; i.e., externally mounted shade cloths which remain in place for extended periods (months). Recent funding obtained from the Fred C. Gloeckner Foundation will be used to finalize design recommendations and to pursue a few remaining unanswered questions.

Misting will not be an answer to all cooling problems, but is an improvement over non-misted external shading. Water quality is still an issue that cannot be avoided. Water with high iron or other mineral content will generally not be suitable for misting. Retractable shade is also an issue. Although there are presently some designs for retractable external shade, I am not aware of any that are commercially available. Since misting, as a solution, is confined to externally mounted shade, further developments (which we will be pursuing) will be necessary before misting can be used when retractable shade is needed.